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Energy Sustainability

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WHY FIRMS INVEST (OR NOT) IN ENERGY EFFICIENCY? A REVIEW OF THE ECONOMETRIC EVIDENCE [*]

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ABSTRACT: The motives that firms have for investing in energy efficiency have been widely analysed in the literature. Particularly, there is a huge literature on barriers to energy efficiency investment and adoption. This paper reviews the econometric analyses carried out in this field. The main objective is to provide a general overview of the state of the econometric literature on the barriers and drivers of energy efficiency. We examine the main features of these studies and particularly the results of the explanatory variables used. We have classified them into three groups, barriers, drivers and firm characteristics. The paper ends with some suggestions for further analysis in order to improve our knowledge of energy efficiency investment.

JEL Codes: Q40, C01
Keywords: Energy efficiency, Literature review

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[*] Acknowledgments: Previous versions of this paper were presented at the XIII Conference of the Spanish Association for Energy Economics (1-2 February 2018, Zaragoza, Spain) and in the 41st International Association for Energy Economics (IAEE) Conference (10-13 June 2018, Groningen, The Netherlands). We are grateful for the comments of the participants. We acknowledge financial support from the Chair of Energy Sustainability (IEB, University of Barcelona). The research leading to these results has received funding from RecerCaixa (RecerCaixa project 2016: The climate change challenge: policies for energy transition).

1. Introduction

The importance of energy efficiency (EE) is beyond doubt. Recent studies try to capture all the benefits related to energy efficiency that go further than plain energy demand reduction and lower GHG emissions (IEA 2015). Energy efficiency is becoming a pillar of the world's energy policy. The European Union has set 'Energy Efficiency First' as one of the three main objectives of its new energy and climate policy proposal "Clean Energy for All Europeans" (EC 2016). Moreover, all major countries have developed consistent energy efficiency policies in recent years. Energy efficiency has emerged as the most cost-effective way to fight against climate change and as a major contributor to total emissions reduction (IEA 2016). The Paris Agreement has reinforced this idea.

Especially important is energy efficiency in the industrial sector. Industry is responsible for more than one third of the worldwide primary energy consumption and the respective energy-related carbon dioxide emissions. The introduction of industrial energy efficiency improvements would deliver great benefits not only in terms of reducing emissions but also in economic competitiveness, economic growth and social welfare. Industrial firms still have room to improve their energy performance particularly in emerging and developing countries. Moreover, the industrial sector is responsible for delivering energy efficiency innovations that will apply to all sectors. Because of all this it is of the highest importance to try to understand the reasons that prevent and explain the adoption of energy efficiency measures in industry.

The literature has widely examined the barriers to energy efficiency improvements in industry. A major concept in these analyses is the so-called energy efficiency gap (Hirst and Brown 1990; Jaffe and Stavins 1994), which proposes a theoretical framework to explain the difference between the socially optimum level of EE investment and that actually observed. The existence of this gap has been mainly explained by the existence of barriers to the adoption of energy efficiency and market failures.

The academic literature has tried to identify and categorize these barriers (Sorrell et al. 2000) and at the same time has expanded the analysis to the drivers that facilitate these investments and the adoption of EE measures (DeCanio and Watkins 1998; Cagno and Trianni, 2013). In recent years, this field of the literature has expanded dramatically, very likely following the impulse given to energy efficiency itself. This literature has focused on ranking barriers and drivers using information obtained through surveys of companies (Cagno et al. 2013; Trianni et al. 2013; Thollander et al. 2013).

Taking into account the considerable growth in the academic production on this subject and the increasing concern about energy efficiency, we try to identify the main variables determining the adoption of energy efficiency through a complete review of the existing literature. The purpose is to characterize the reasons that push forward or slow down energy efficiency deployment and how the different features of the firms have an influence. The final aim is to propose policy recommendations and to provide suggestions for future research.

In this literature, only a part of the studies have an econometric treatment. In contrast to a recent review (Solnordal and Foss 2018) this review focuses exclusively on papers that use econometric methods. Although other methods, like case studies, are very useful in analysing energy efficiency activities, the purpose of econometric methods is to provide general evidence about causal relationships between different variables and therefore they may provide more robust and general results about the determinants of energy efficiency. Reviews of the literature covering the econometric evidence are quite frequently done in other fields of economics (see, among others, David et al. 2000; del Río et al. 2016).

2. Methodology

To identify the articles explaining the barriers, drivers and firm characteristics that affect investment by firms in energy efficiency we have designed a bibliometric analysis composed of several steps. The final objective is to obtain a definitive list of papers on the selected topic that have an econometric treatment. First, we have carried out a Scopus search, in a similar way as other reviews (del Río et al. 2016) that have applied the same technique in order to obtain a preliminary list of papers. Scopus defines itself as the largest database of peer-reviewed literature ensuring the most exhaustive search of academic articles. Comparison of the use of Scopus with the other main database of academic literature (Web of Science) shows that the results are similar (Gavel and Iselid 2008). To perform the Scopus search we chose the following keywords “energy efficiency barriers” then added new words to create new searches such as “industrial, drivers, investment, measures and adoption”. In order to check the results obtained we have introduced the same keywords in Google Scholar. Using this double source of information increases the reliability of the search carried out and minimizes the possibility of missing some important papers. The final step was to go through the literature cited in the most relevant papers found. An important source was an overview of empirical studies addressing the role of barriers to adopting energy efficiency measures (Fleiter et al. 2012).

FIGURE 1

With this final step, we have compiled a list of 86 papers referring to barriers, drivers and characteristics affecting investment and the adoption of energy efficiency measures in companies. Most of the papers have been published in the last ten years (70 out of 86). This could be considered evidence of the importance that energy efficiency has gained recently and the reaction of academia in focusing research on this topic. Energy Policy, Energy Efficiency and the Journal of Cleaner Production are the journals that have published most papers on energy efficiency barriers and drivers (15, 14 and 12 respectively, more than half of the total papers). The other half is distributed between the other 27 journals and working paper series. This fact denotes the interest in this issue beyond energy related journals.

In this review we are only interested on those papers that include an econometric analysis. After selecting those papers from the long list at the end of the process we had 24 papers referring to firms' decisions on energy efficiency with econometric treatment (see a list of these papers in Annex 1). The publication of these papers follows the same trend and most of them have been published in the last ten years. Energy Policy, Energy Efficiency and the Journal of Cleaner Production are again the leading journals with 4, 3 and 2 publications, together with Energy Economics with 3 publications.

TABLE 1

3. Main characteristics of the empirical literature on energy efficiency

3.1. Geographical scope

The papers selected focus mostly on Europe and the US with some minor representation of studies covering developing countries. The countries most targeted by the study of energy efficiency are Germany (Olsthoorn et al. 2017; Hertel and Menrad 2016; Fleiter et al. 2012; Schleich 2009; Schleich and Gruber 2008) and the US (Blass et al. 2014; Abadie et al. 2012; Muthulingam et al. 2011; Anderson and Newell 2004; DeCanio and Watkins 1998) with five articles each. The interest in Germany could be explained by the importance of the industrial sector but also by the availability of data. This is also the case of the US where the IAC program of energy audits provides the data for four of the five papers published.

Other countries in Europe have called the attention of researchers. The Netherlands is analysed in three studies (Aramyan et al. 2007; Diederen et al. 2003; De Groot et al. 2001) with the focus on the horticultural sector. Papers from Greece (Kounetas et al. 2011; Sardianou 2008), Belgium (Venmans 2014) and Spain (Costa-Campi et al. 2015) have also used econometric analyses on different aspects related to EE adoption. On the other hand, some studies have focused on emerging and developing countries like China (Kostka et al. 2013) and Brazil (Sola and Xavier, 2007). The work of the World Bank and the UNIDO (United Nations Industrial Development Organisation) making information available has made econometric research possible on this topic in developing countries with studies focused in either big (Cantore and Cali, 2011) or small groups (Hochman and Timilsina 2017; Cantore 2017 and 2011). The choice of these countries for an analysis of energy efficiency seems related with the availability of data, which is also related to the interest of those countries in promoting energy efficiency.

3.2. Data

The principal source of information used in these studies is survey data usually obtained from structured questionnaires through interviews or email. Public programs related with energy audits or policies promoting the adoption of energy saving technologies are another important source of information. The number of observations is higher for those using public program information or information from public institutions rather than direct surveys organized privately. The papers using the IACs energy audit program data have the greatest number of observations (Anderson and Newell 2004; Muthulingam et al. 2011; Abadie et al. 2012; Blass et al. 2014). In the case of surveys for collecting information about energy efficiency, the number of observations (responses of the firms) is much lower although it is appropriate to highlight the work of Olsthoorn et al. (2017), Schleich (2009) and Schleich and Gruber (2008) covering over 2000 firms.

Apart from these main sources of data we have also found other data used. In the case of developing countries it is important to highlight, as mentioned above, the task done by the World Bank and UNIDO in gathering information on energy efficiency for several developing countries. For instance, in Cantore (2011; 2017) the information collected by UNIDO through surveys is employed for a discrete choice analysis on barriers to energy efficiency in Vietnam, Moldova, Thailand and the Philippines. The most recent paper is Hochman and Timilsina (2017) in which, as a result of a World Bank project, they have collected information on barriers to energy efficiency for more than 500 firms in Ukraine.

Public programs have also been an important source of information for this literature. Apart from the IACs US program already mentioned, other sources of data were the German energy audit program (Fleiter et al. 2012), the Greek incentive schemes for the adoption of energy saving technologies (Kounetas et al. 2011) and the Green Lights Program of the EPA in the US (DeCanio and Watkins 1998). In addition, official data provided by the Farm Accountancy Data Network of the Agricultural Economics Research Institute (LEI) was used in the papers about the horticultural sector in the Netherlands. Finally, Khanna and Zilberman (1999) used information from the central electricity authority.

Another source of data is the Community Innovation Survey (CIS) for Spain (Costa-Campi et al. 2015). Other papers using survey data, usually complemented with face-to-face interviews, are Hertel and Menrad (2016) for the German horticultural sector, Venmans (2014) for the construction materials sector in Belgium, Kostka et al. (2013) using a bank to obtain the information for a Chinese region, Sardianou (2008) for the industrial sector in Greece and De Groot et al. (2001) for the Netherlands.

We can conclude from this section that sources of information are very important for the development of this research topic. Having good data on energy efficiency is still rare and mostly dependent on the action of public institutions. Collecting information in energy efficiency is costly and the interest of companies in responding to surveys is not very high. Also the accuracy for research purposes of the information coming from surveys has been questioned. This is an additional factor that may hamper the development of the literature on this issue, despite its importance.

3.3. Models employed

The econometric models employed are related to the characteristics of the dependent variable. In many cases, the variable for capturing EE investment or decisions is binary and therefore logit and probit models have been frequently used. Only in a few cases have authors used Ordinary Least Squares (OLS) or Tobit methods to carry out the estimations.

Another relevant characteristic of the econometric models employed is that most of them are cross-section analyses. The lack of information has made it very difficult to use, except in a few cases, panel data approaches. This is an important limitation because it seems quite important to take the dynamic issues of EE investments into account, as well as some non-observable

characteristics of the firms in order to improve the accuracy of the estimations and to obtain causal relationships and not only correlations.

3.4. Variables

Dependent Variables

Different dependent variables have been used to measure EE. The most frequent is a dichotomous variable regarding the adoption or not of energy efficiency technologies. Alternatively, investment in energy efficiency is also common. Less frequent are the use of the barriers or other options such as energy efficiency as on objective of innovation, the ratio between firms' profitability and energy intensity and the technical characteristics of a certain technology.

In general, the adoption of energy efficiency measures or recommendations is the most common dependent variable (Olsthoorn et al. 2017; Hertel and Menrad 2016; Blass et al. 2014; Abadie et al. 2012; Fleiter et al. 2012; Kounetas et al. 2011; Cantore 2011; Muthulingam et al. 2011; Anderson and Newell 2004; Diederen et al. 2003; DeCanio and Watkins 1998). These studies try to explain the reasons why firms introduce energy efficiency improvements or not from different perspectives. The dependent variable is not always exactly "adoption" as is shown in Table 1. Schleich (2009) and Schleich and Gruber (2008) use the concept of "active" and "inactive" adopters of energy efficiency measures, considering active adopters to be those implementing more than 50% of the measures feasible for that company. In addition, the difference between planned and executed investment in energy efficiency is another recurrent dependent variable used to look at barriers and drivers (Hochman and Timilsina 2017; Cantore, 2017; Aramyan et al. 2007).

Barriers as dependent variables have been used in three other studies where the authors examine the relationship of each barrier with different characteristics of firms (Olsthoorn et al. 2017; Venmans 2014; Sardianou 2008). Another two articles use information on energy efficiency measures as dependent variables for assessing the influence of information on the firms' investment decision process (Kounetas et al. 2011; De Groot et al. 2001). Other dependent variables used for the econometric analysis of the determinants of energy efficiency are the firm's profitability (Cantore and Cali 2011), energy consumption (Khanna and Zilberman 1999), energy saving activities (Kostka et al. 2013), EE being an innovation objective, motor energy

performance (Sola and Xavier 2007) and motivations for introducing EE improvements (Costa-Campi et al. 2015).

Explanatory Variables

We have identified 84 different explanatory variables used in the 24 papers covered in this review (see Tables 2 and 3). These variables mainly capture firm characteristics, drivers and barriers. The set of barriers included in some articles is larger but not all of them are used as explanatory variables in the econometric analyses. Instead the information corresponding to some of these barriers was summarized through Principal Component Analysis for introduction into the regressions or was not included in the econometric analysis at all.

Many of the papers use the performance of the firm as an explanatory variable. Firms' revenues and sales are the variables chosen for that purpose and they are in most cases significant (Hochman and Timilsina 2017; Costa-Campi et al. 2015; Blass et al. 2014; Kostka et al. 2013; Muthulingam et al. 2011; Aramyan et al. 2007; Diederen et al. 2003; De Groot et al. 2001; DeCanio and Watkins, 1998). The paper by DeCanio and Watkins (1998) is an exception in that it introduces a great number of variables to assess the economic performance of firms and to examine their energy efficiency investment behaviour.

The most common explanatory variable regarding the characteristics of the firms is size (Olsthoorn et al. 2017; Cantore 2017; Costa-Campi et al. 2015; Blass et al. 2014; Fleiter et al. 2012; Kounetas et al. 2011; Cantore 2011; Cantore and Cali 2011; Muthulingam et al. 2011; Schleich 2009; Sardianou 2008; Schleich and Gruber 2008; De Groot et al. 2001; DeCanio and Watkins 1998). Size is usually measured by the number of employees. In most cases it is found to be significant with a positive effect on energy efficiency adoption.

Other firm characteristics commonly introduced as explanatory factors of EE in firms are exports, public ownership and being a subsidiary (Hochman and Timilsina 2017; Costa-Campi et al. 2015; Kounetas et al. 2011; Cantore and Cali 2011; De Groot et al. 2001; Khanna and Zilberman 1999). Propensity to export and being part of a corporation seems to influence the introduction of energy efficiency measures while public or private ownership and being part-owned by foreign capital are found not to be significant in most cases. The age of the firm is also frequently used. The analyses usually found it was not significant in explaining energy efficiency investments (Costa-Campi et al. 2015; Kostka et al. 2013; Cantore and Cali 2011; Sardianou 2008; Aramyan et al. 2007; Khanna and Zilberman 1999).

Another set of variables refers specifically to production plants. For instance, some studies found an explanatory capacity in the fact that facilities are rented or in the size of the plant (Hochman and Timilsina 2017; Olsthoorn et al. 2017; Blass et al. 2014; Fleiter et al. 2012; Schleich 2009; Schleich and Gruber 2008; Sardianou 2008; Aramyan et al. 2007; Diederen et al. 2003). There is great interest in the effects of specific energy aspects and the management of the firms. The introduction of an Energy Management System or contracting an Energy Manager as well as the implementation of an energy audit or the obtention of an energy certification such as the ISO 50001 have been considered characteristics that may influence the energy efficiency behaviour of the firms (Hochman and Timilsina 2017; Olsthoorn et al. 2017; Cantore 2017; Kostka et al. 2013; Fleiter et al. 2012; Kounetas et al. 2011; Cantore 2011; Cantore and Cali, 2011). The results show that all of these except the introduction of an energy management system are significant in explaining the adoption of energy efficiency measures. It is important to highlight that this group of variables is to be found in recent studies, which shows the newness of this type of measure. In this group, we can also include the energy costs of the company, which are considered an explanatory variable in several studies. Whether measured as total energy cost or by employees, most of the papers find it significant in explaining the concern of the company about energy efficiency (Hochman and Timilsina 2017; Olsthoorn et al. 2017; Blass et al. 2014; Kostka et al. 2013; Fleiter et al. 2012; Muthulingam et al. 2011; Schleich 2009; Schleich and Gruber 2008; Sardianou 2008; Anderson and Newell 2004; De Groot et al. 2001).

Different variables of innovation have been used as potential energy efficiency drivers. Having an R&D department, the introduction of innovations or investing in internal or external R&D are some of the variables used to try to explain the effects of innovation on energy efficiency. These variables have been found to be not significant showing that to be an innovator is not a driver of energy efficiency improvements in a firm. Only the paper of Costa-Campi et al. (2015) shows a positive relationship between innovation, when measured through the acquisition of new machinery, and energy efficiency. However the variable capturing R&D was not significant.

Finally, it is interesting to highlight the variables about energy efficiency measures used to explain EE implementation in firms. For instance, the payback, the cost and the potential savings that EE measures can produce are used in several studies as determinants of the adoption of energy efficiency measures (Blass et al. 2014; Abadie et al. 2012; Fleiter et al. 2012; Muthulingam et al. 2011; Anderson and Newell 2004). The results show that they are significant and have a positive relationship with EE improvement in firms.

Moreover, some barriers are used as explanatory variables (Hochman and Timilsina 2017; Olsthoorn et al. 2017; Cantore 2017; Costa-Campi et al. 2015; Kostka et al. 2013; Fleiter et al. 2012; Cantore 2011; Cantore and Cali, 2011; Schleich 2009; Schleich and Gruber 2008; Aramyan et al. 2007). As is pointed out above, certain barriers have been introduced in the econometric regressions as explanatory variables, but also in some cases as dependent variables.

The barriers considered are of an economic, behavioural, informational and regulatory nature (Cagno et al. 2013; Sorrell et al. 2000). The EE barriers frequently introduced in the econometric studies are internal or external financial constraints, a low prioritisation of energy cost or energy consumption in the company, a lack of information about existing or new technologies to improve EE, existing laws and regulations and having previously invested in EE. The results do not provide clear evidence about the relevance of these barriers in explaining energy efficiency decisions in firms. In some cases they are significant while in others not. That is the case for financial and informational barriers where there is no clear evidence about their role in EE investment. Regulatory barriers are only significant in explaining energy efficiency in one out of four papers. On the other hand, having previously invested in EE is the only barrier with clear statistical significance. Lack of time, uncertainty or considering EE when buying new equipment are used in other studies with significant results in the first case.

Nonetheless, the use of barriers in these papers is much more extensive than it is only in the econometric estimations. We have found barriers in 13 out of the 24 papers in this review (Hochman and Timilsina 2017; Olsthoorn et al. 2017; Cantore 2017; Hertel and Menrad 2016; Venmans 2014; Fleiter et al. 2012; Cantore 2011; Schleich 2009; Sardianou 2008; Schleich and Gruber 2008; Sola and Xavier 2007; Anderson and Newell 2004; De Groot et al. 2001), with an average of 20 barriers listed in each one. In some of these papers, the econometric treatment is complemented with a ranking of importance of barriers.

TABLES 2 AND 3

4. Conclusions

In this paper we have reviewed the econometric evidence on the determinants of the adoption of energy efficiency measures and investments in firms. The review has focused not only on barriers to EE but also on the drivers and other characteristics of the firms as potential

explanatory variables. There has been a significant rise in the number of publications in this field related with the growing importance of energy efficiency at business and at policy level as a very important way to face the challenge of climate change.

The main conclusions obtained from this review that also provide some suggestions for future research are the following:

First, very few of the empirical papers provide a theoretical framework. The use of theoretical frameworks to support the empirical model would help to show clearly what the factors are that affect the EE decisions of firms and the relationships between the different variables.

Second, the analyses carried out are clearly dependent on the available data. More research has been done in US and Germany due to the availability of information from public programs (Energy audit programs) and private surveys. The lack of data is a significant limitation in this field of research and the research questions that many papers propose are therefore restricted to the available data in some specific surveys or public programs. In particular, the availability of panel data would make it easier to perform more robust econometric analyses and to take the dynamic process of EE into account. It would also help to minimise endogeneity issues, which are a significant concern in this empirical literature.

Third, there is some heterogeneity in the dependent variables used to measure EE, as Solnordal and Foss (2018) also point out. In addition, many independent variables, not always with the same definition, have been used. This makes it quite difficult to compare some results of the econometric analyses and to obtain robust conclusions about the main barriers and drivers of energy efficiency.

Fourth, it would be convenient to use the two main dependent variables, the adoption of EE measures (a binary variable) and the amount of the investments in EE, jointly in the econometric analysis. This could help a better understanding of the role of the barriers and some specific characteristics of the firms regarding their behaviour in EE.

Finally, to improve EE in firms requires, as pointed out by many papers, a policy mix with the use of different instruments. Nevertheless, very few papers have carried out an evaluation analysis of the impact of these instruments. In addition, it seems convenient to analyse potential heterogeneities in the behaviour of the firms regarding EE in more detail. Industry differences in particular seem to be quite important.

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Table 1
Barriers, drivers and determinants of energy efficiency with firm level data

Main Features	Hochman & Timilsina (2017)	Olsthoorn et al. (2017)	Cantore (2017)	Hertel & Menrad (2016)	Costa-Campi et al. (2015)	Blass et al. (2014)	Venmans (2014)	Kostka et al. (2013)	Abadie et al. (2012)	Fleiter et al. (2012)	Kounetas et al. (2011)	Cantore (2011)
Econometric method (model)	generalized ordered logit model	Random-effects probit model / univariate probit models / multivariate probit model	logit model	partial least squares (PLS)	logit model	OLS and logit regression models	OLS	OLS	Tobit model	fractional logit model (FLM)	ordinary probit / ordered probit model	logit model
Geographical scope	Ukraine	Germany	Vietnam / Filipinas / Moldova	Germany (Bavaria)	Spain	US (California and Ohio)	Belgium	China (Zhejiang Province)	US	Germany	Greece	Viet Nam, Moldova, Thailand, Philippines
Dependent Variable	Amount invested in EE in past 5 years	Adoption and barriers to adoption EEM	considering to invest in EE in next 5 years?	adoption of energy-efficient technology	firm seeks EE as an objective of innovation	adoption EE recom. - savings / costs - average payback recom.	motivations and barriers to EE	company's total energy saving activities (TESA)	choice of implementing or not EE recom.	adoption rate per firm	EETs' adopters into prior informed and prior non-informed	Technology adoption = YES or NO
Data source	Survey data; face-to-face and mail interviews; World Bank	Survey data on adoption of four different crosscutting types of EEMs	Survey data collected by UNIDO on barriers to the adoption of EEMs	survey data; face-to-face interviews; with managers of SMEs	Panel data from the Community Innovation Survey PITEC	Audit data IACs Program EE recomendations	Survey data; face-to-face interviews	Survey data; face-to-face interviews	Audit data IACs Program EE recom.	German energy audit program	Greek incentives schemes for the adoption of energy saving technologies	World Bank Enterprise Survey
Sample Size	509 firms	2440 firms	214 firms	104 managers	4458 firms	752 firms	16 firms (N=61 projects)	480 firms	14890 assesments	542 firms	298 firms	116 observations

Main Features	Cantore & Cali (2011)	Muthulingam et al. (2011)	Schleich (2009)	Sardianou (2008)	Schleich & Gruber (2008)	Sola & Xavier (2007)	Aramyan et al. (2007)	Anderson & Newell (2004)	Diederen et al. (2003)	De Groot et al. (2001)	Khanna & Zilberman (1999)	DeCanio & Watkins (1998)
Econometric method (model)	fixed effect estimation	probit instrumental variable model	Logit estimation	probit models	Logit model	simple linear regression	combination probit model + truncated regression model	fixed effects logit estimation	logit model	OLS	(OLS) Panel Data	discrete choice regression
Geographical scope	29 developing countries	US	Germany	Greece	Germany	Brazil (Parana State)	Netherlands	US	Netherlands	Netherlands	India	US
Dependent Variable	firm's profitability / Energy intensity	whether a recommendation is adopted or not	"active" and "inactive" adopters of energy efficiency measures	perceived knowledge and each barrier	"active" and "inactive" adopters of energy efficiency measures	energy loss per motor	investments in energy-saving installations	whether or not a plant adopted a recommended project	whether the firm had adopted the technology	knowledge existing and new technologies	auxiliary and energy consumption	Green Lights membership
Data source	World Bank enterprise surveys	Audit data IACs Program EE recomendations	cross-sectional survey / personal interviews / commercial and services sector (Geiger et al., 1999)	survey / face-to-face interviews	cross-sectional survey / personal interviews / commercial and services sector (Geiger et al., 1999)	four supervisors of production and maintenance areas answered the questionnaires	Farm Accountancy Data Network of the Agricultural Economics Research Institute (LEI).	Audit data IACs Program EE recomendations	Farm Accountancy Data Network of the Agricultural Economics Research Institute (LEI).	15 pages survey plant locations in 9 industrial sectors	Central electricity authority	Green Lights Program EPA / Disclosure database compiled from reports to the SEC
Sample Size	-	Over 13000 firms	2848 firms	50 of 779 firms	2848 firms	30 elements from 40 evaluations + 486 engines	1879 observations on 397 farms	39,920 projects from 9034 plants	433+170 observations	135 firms	63 firms (240 observations plan level)	268 firms

Source: Own elaboration.

Table 2 Explanatory Variables

	Hochman & Timilsina (2017)	Olsthoorn et al. (2017)	Cantore (2017)	Hertel & Menrad (2016)	Costa-Campi et al. (2015)	Blass et al. (2014)	Venmans (2014)	Kostka et al. (2013)	Abadie et al. (2012)	Fleiter et al. (2012)	Kounetas et al. (2011)	Cantore (2011)
Annual revenues	*(+)							*(+)				
Sales					*(+)	NS						
Employees (size)		NS	NS		*(+)	NS				NS	*(+)	NS
Exports					*(+)						*(+)	
Private ownership	NS				NS							
Foreign ownership	*(+)				NS							
Subsidiary (group)		*(-)			NS							
Facility rented	NS	*(-)								NS		
Info Electricity vs Thermal												
EMS		NS	NS							NS		NS
Energy manager		*(+)						NS			*(+)	
Energy audit	*(+)	*(+)	*(+)									* (+)
EE external cooperation											*(+)	
Clean energy used		*(+)										
Manufacturing sectors		*(-)						*(+)				
Share of energy costs	*(+)											
Elec. cost per employee		*(+)										
Total energy costs		*(+)				NS		*(+)		*(+)		
Successor												
Age of the firm					NS			NS				
Plant area						*(+)						
Location											*(+)	NS
Gross investment in tangible assets					*(+)						*(+)	*(+)
Top management						NS					*(-)	
Payback time									*(-)	NS		
Total saving identified/firm sales						NS			*(+)	NS		
EE Cost						*(-)			*(-)	*(-)		
Number of recommendations						NS			*(-)			
Serial position of recommendation						*(-)						
Financial barriers	*(-)							NS		*(-)		
Low priority Energy costs	NS	*								NS		
Knowledge barriers	*(-)							*(+)		NS		
Existing laws and regulation			NS		*(+)							NS
Staff awareness programs			NS									NS
Energy management innovation			*(+)		*(+)							* (+)
Energy reduction targets			NS									NS
Certification			*(-)									* (-)
Investments in EE in the last 2 years			NS							NS		* (+)
Lack of time												
Uncertainity on Energy costs												
EE in new equipment												
Component 1: external conditions			NS									NS
Component 2: microeconomic constraints			*(-)									*(-)

Source: Own elaboration.

Table 2 Explanatory Variables (Continues)

	Cantore & Cali (2011)	Muthulingam et al. (2011)	Schleich (2009)	Sardianou (2008)	Schleich & Gruber (2008)	Sola & Xavier (2007)	Aramyan et al. (2007)	Anderson & Newell (2004)	Diederen et al. (2003)	De Groot et al. (2001)	Khanna & Zilberman (1999)	DeCanio & Watkins (1998)
Annual revenues							*(+)		*(+)	NS		*(+)
Sales		NS										
Employees (size)	*(+)	NS	*(+)	*(-)	*(+)					*(+)		*(+)
Exports	*(+)									*(+and-)		
Private ownership											*(+)	
Foreign ownership	*(+)											
Subsidiary (group)												
Facility rented			*(-)		*(-)							
Info Electricity vs Thermal			*(-)		*(-)							
EMS												
Energy manager												
Energy audit												
EE external cooperation												
Clean energy used												
Manufacturing sectors												
Share of energy costs										*(+)		
Elec. cost per employee			*(+)									
Total energy costs		*(+)		NS	*(+)			*(+)				
Successor							*(+)		NS			
Age of the firm	*(+)			NS			NS				*(+)	
Plant area				*(-)			*(+)		*(+)			
Location												
Gross investment in tangible assets				*(-)						*(+)		
Top management												
Payback time		*(-)						*(-)				
Total saving identified/firm sales		*(+)						*(+)				
EE Cost		*(-)						*(-)				
Number of recommendations		*(-)										
Serial position of recommendation		*(-)										
Financial barriers							NS					
Low priority Energy costs			*(-)		*(-)							
Knowledge barriers			NS		*(+ and -)							
Existing laws and regulation												
Staff awareness programs												
Energy management innovation												
Energy reduction targets												
Certification	NS											
Investments in EE in the last 2 years												
Lack of time			*(-)		*(-)							
Uncertainity on Energy costs			NS		*(+ and -)		NS					
EE in new equipment			NS		*(+)							
Component 1: external conditions												
Component 2: microeconomic constraints												

Source: Own elaboration.

Table 3 Explanatory Variables in a single article

	Hochman & Timilsina (2017)	Olsthoorn et al. (2017)	Costa-Campi et al. (2015)	Blass et al. (2014)	Kostka et al. (2013)	Abadie et al. (2012)	Fleiter et al. (2012)	Kounetas et al. (2011)	Muthulingam et al. (2011)	Sardianou (2008)	Aramyan et al. (2007)	De Groot et al. (2001)	Khanna & Zilberman (1999)	DeCanio & Watkins (1998)
Company earnings per share														NS
Industry earnings per share														*(+)
Number of shares divided by one														*(+)
Forecasted earnings growth														*(-)
Stock price														*(+)
Disposable														*(-)
Net income														NS
Number of shares owned by staff														*(-)
Total debt														NS
Solvency											*(+)			
Heating system external		*(-)												
High quality coal													*(-)	
Family size											*(+)			
Education										*(-)				
Foreing provider													*(+)	
Company growth					*(+)									
Degree of competition												*(+and-)		
R&D Deparment								NS						
Introduction of innovation								*(-)						
Investment in internal R&D			NS											
Investment in external R&D			NS											
Future invesment in tangible assets								*(-)						
Modernity of machinery											*(+)			
Modernity of installations											*(+)			
Top operations managers				*(+)										
Top general managers				NS										
Average payback of an assessment				*(-)										
Variance of Payback									*(-)					
State GDP						*(-)								
Emissions						*(+)								
Year						NS								
Access to energy finance					*(+)									
Hidden costs barriers	*(-)													
Split barriers	NS													
Firm's bureaucracy	NS													
Audit quality							*(+)							
Production interruption and product quality losses							NS							
Future invesment in EE								*(+)						
Low profit							NS							
Public funding			NS											
objective of innovation "reduce environmental impact"			*(+)											

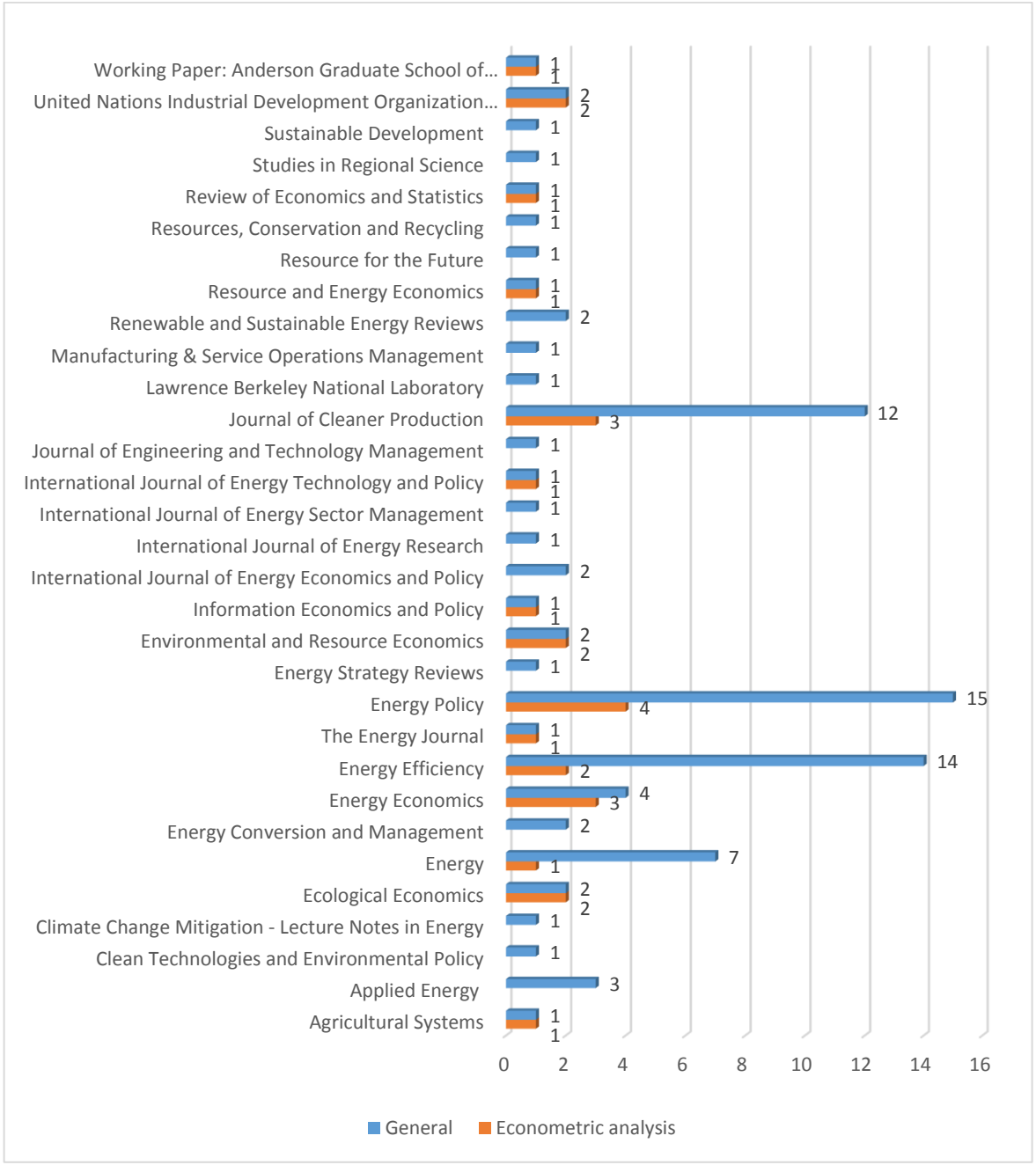
Source: Own elaboration.

Annex 1. List of papers selected for the survey

	Title	Authors	Year	Journal	Model
01	Energy efficiency barriers in commercial and industrial firms in Ukraine: An empirical analysis	Hochman, G., Timilsina, G.R.	2017	Energy Economics	Generalized ordered logit model
02	Adoption of Energy Efficiency Measures for Non-residential Buildings: Technological and Organizational Heterogeneity in the Trade, Commerce and Services Sector	Olsthoorn, M. Schleich, J. Hirzel, S.	2017	Ecological Economics	Random-effects probit model / Full multivariate probit model
03	Factors affecting the adoption of energy efficiency in the manufacturing sector of developing countries	Cantore, N.	2017	Energy Efficiency	Logit model
04	Adoption of energy-efficient technologies in German SMEs of the horticultural sector—the moderating role of personal and social factors	Hertel, M., Menrad, K.	2016	Energy Efficiency	Partial least squares (PLS)
05	Energy efficiency determinants: an empirical analysis of Spanish innovative firms	M.T. Costa-Campi, J. García-Quevedo, A.Segarra	2015	Energy Policy	Logit model
06	Top management and the adoption of energy efficiency practices: evidence from small and medium-sized manufacturing firms in the US	V. Blass, C.J. Corbett, M.A. Delm as, S.Muthulingam	2014	Energy	OLS and logit regression models
07	Triggers and barriers to energy efficiency measures in the ceramic, cement and lime sectors	Venmans, F.	2014	Journal of Cleaner Production	OLS
08	Barriers to increasing energy efficiency: evidence from small-and medium-sized enterprises in China.	Kostka, G., Moslener, U., & Andreas, J.	2013	Journal of Cleaner Production	Standard OLS models
09	Determinants of energy efficiency investments in the US	L.M. Abadie, R.A. Ortiz, I. Galarraga	2012	Energy Policy	Tobit model / Probit
10	Adoption of energy-efficiency measures in SMEs-An empirical analysis based on energy audit data from Germany	Fleiter, T. Schleich, J. Ravivanpong, P.	2012	Energy Policy	Fractional logit model
11	Promoting energy efficiency policies over the information barrier	Kounetas, K., Skuras, D., Tsekouras, K.	2011	Information Economics and Policy	Ordinary probit
12	Synthesis: Energy efficiency in developing countries for the manufacturing sector	Cantore, N.	2011	UNIDO	Logit model
13	Profitability and energy efficiency: a firms fixed effect approach	Cantore, N., & Cali, M.	2011	UNIDO	Fixed Effects
14	Investment in Energy Efficiency by Small and Medium-Sized Firms: An Empirical Analysis of the Adoption of Process Improvement Recommendations	Muthulingam, S., Corbett, C.J., Benartzi, S., Oppenheim, B.	2011	Working Paper: Anderson Graduate School of Management	Instrumental Variables Probit Model
15	Barriers to energy efficiency: A comparison across the German commercial and services sector	Schleich, J.	2009	Ecological Economics	Standard Logit and Probit models
16	Barriers to industrial energy efficiency investments in Greece	Sardianou, E.	2008	Journal of Cleaner Production	Probit models
17	Beyond case studies: Barriers to energy efficiency in commerce and the services sector	Schleich, J., Gruber, E.	2008	Energy Economics	Logit models
18	Organizational human factors as barriers to energy efficiency in electrical motors systems in industry	Sola, A.V.H., Xavier, A.A.P.	2007	Energy Policy	Simple linear regression analysis
19	Factors underlying the investment decision in energy-saving systems in Dutch horticulture	L.H. Aramyan, A.G.J.M. Lansink, J.A.A.M. Verstegen	2007	Agricultural Systems	Cragg's model combination of probit model and truncated regression model.
20	Information programs for technology adoption: the case of energy-efficiency audits	S.T. Anderson, R.G. Newell	2004	Resource and Energy Economics	Maximum likelihood / Conditional fixed effects logit estimator
21	Returns on investments in energy-saving technologies under energy price uncertainty in Dutch greenhouse horticulture	P. Diederen, F. van Tongeren, H. van der Veen	2003	Environmental and Resource Economics	
22	Energy saving by firms: Decision-making, barriers and policies	De Groot, H.L.F., Verhoef, E.T., Nijkamp, P.	2001	Energy Economics	OLS with sector dummies
23	Barriers to energy-efficiency in electricity generation in India	Khanna, M., Zilberman, D.	1999	Energy Journal	OLS
24	Investment in energy efficiency: do the characteristics of firms matter?	DeCanio, S. J., & Watkins, W. E.	1998	Review of Economics and Statistics	Logit

Source: Own elaboration.

Fig. 1. Journals with articles on barriers, drivers and determinants of energy efficiency (general and only with econometrical treatment).
Source: Own elaboration using Scopus data and Google Scholar.



2013

2013/1, Sánchez-Vidal, M.; González-Val, R.; Viladecans-Marsal, E.: "Sequential city growth in the US: does age matter?"
2013/2, Hortas Rico, M.: "Sprawl, blight and the role of urban containment policies. Evidence from US cities"
2013/3, Lampón, J.F.; Cabanelas-Lorenzo, P-; Lago-Peñas, S.: "Why firms relocate their production overseas? The answer lies inside: corporate, logistic and technological determinants"
2013/4, Montolio, D.; Planells, S.: "Does tourism boost criminal activity? Evidence from a top touristic country"
2013/5, Garcia-López, M.A.; Holl, A.; Viladecans-Marsal, E.: "Suburbanization and highways: when the Romans, the Bourbons and the first cars still shape Spanish cities"
2013/6, Bosch, N.; Espasa, M.; Montolio, D.: "Should large Spanish municipalities be financially compensated? Costs and benefits of being a capital/central municipality"
2013/7, Escardíbul, J.O.; Mora, T.: "Teacher gender and student performance in mathematics. Evidence from Catalonia"
2013/8, Arqué-Castells, P.; Viladecans-Marsal, E.: "Banking towards development: evidence from the Spanish banking expansion plan"
2013/9, Asensio, J.; Gómez-Lobo, A.; Matas, A.: "How effective are policies to reduce gasoline consumption? Evaluating a quasi-natural experiment in Spain"
2013/10, Jofre-Monseny, J.: "The effects of unemployment benefits on migration in lagging regions"
2013/11, Segarra, A.; García-Quevedo, J.; Teruel, M.: "Financial constraints and the failure of innovation projects"
2013/12, Jerrim, J.; Choi, A.: "The mathematics skills of school children: How does England compare to the high performing East Asian jurisdictions?"
2013/13, González-Val, R.; Tirado-Fabregat, D.A.; Viladecans-Marsal, E.: "Market potential and city growth: Spain 1860-1960"
2013/14, Lundqvist, H.: "Is it worth it? On the returns to holding political office"
2013/15, Ahlfeldt, G.M.; Maennig, W.: "Homevoters vs. leasevoters: a spatial analysis of airport effects"
2013/16, Lampón, J.F.; Lago-Peñas, S.: "Factors behind international relocation and changes in production geography in the European automobile components industry"
2013/17, Guío, J.M.; Choi, A.: "Evolution of the school failure risk during the 2000 decade in Spain: analysis of Pisa results with a two-level logistic mode"
2013/18, Dahlby, B.; Rodden, J.: "A political economy model of the vertical fiscal gap and vertical fiscal imbalances in a federation"
2013/19, Acacia, F.; Cubel, M.: "Strategic voting and happiness"
2013/20, Hellerstein, J.K.; Kutzbach, M.J.; Neumark, D.: "Do labor market networks have an important spatial dimension?"
2013/21, Pellegrino, G.; Savona, M.: "Is money all? Financing versus knowledge and demand constraints to innovation"
2013/22, Lin, J.: "Regional resilience"
2013/23, Costa-Campi, M.T.; Duch-Brown, N.; García-Quevedo, J.: "R&D drivers and obstacles to innovation in the energy industry"
2013/24, Huisman, R.; Stradnic, V.; Westgaard, S.: "Renewable energy and electricity prices: indirect empirical evidence from hydro power"
2013/25, Dargaud, E.; Mantovani, A.; Reggiani, C.: "The fight against cartels: a transatlantic perspective"
2013/26, Lambertini, L.; Mantovani, A.: "Feedback equilibria in a dynamic renewable resource oligopoly: pre-emption, voracity and exhaustion"
2013/27, Feld, L.P.; Kalb, A.; Moessinger, M.D.; Osterloh, S.: "Sovereign bond market reactions to fiscal rules and no-bailout clauses – the Swiss experience"
2013/28, Hilber, C.A.L.; Vermeulen, W.: "The impact of supply constraints on house prices in England"
2013/29, Revelli, F.: "Tax limits and local democracy"
2013/30, Wang, R.; Wang, W.: "Dress-up contest: a dark side of fiscal decentralization"
2013/31, Dargaud, E.; Mantovani, A.; Reggiani, C.: "The fight against cartels: a transatlantic perspective"
2013/32, Saarimaa, T.; Tukiainen, J.: "Local representation and strategic voting: evidence from electoral boundary reforms"
2013/33, Agasisti, T.; Murtinu, S.: "Are we wasting public money? No! The effects of grants on Italian university students' performances"
2013/34, Flacher, D.; Harari-Kermadec, H.; Moulin, L.: "Financing higher education: a contributory scheme"
2013/35, Carozzi, F.; Repetto, L.: "Sending the pork home: birth town bias in transfers to Italian municipalities"
2013/36, Coad, A.; Frankish, J.S.; Roberts, R.G.; Storey, D.J.: "New venture survival and growth: Does the fog lift?"
2013/37, Giulietti, M.; Grossi, L.; Waterson, M.: "Revenues from storage in a competitive electricity market: Empirical evidence from Great Britain"

2014

2014/1, Montolio, D.; Planells-Struse, S.: "When police patrols matter. The effect of police proximity on citizens' crime risk perception"
2014/2, Garcia-López, M.A.; Solé-Ollé, A.; Viladecans-Marsal, E.: "Do land use policies follow road construction?"
2014/3, Piolatto, A.; Rablen, M.D.: "Prospect theory and tax evasion: a reconsideration of the Yitzhaki puzzle"
2014/4, Cuberes, D.; González-Val, R.: "The effect of the Spanish Reconquest on Iberian Cities"
2014/5, Durán-Cabré, J.M.; Esteller-Moré, E.: "Tax professionals' view of the Spanish tax system: efficiency, equity and tax planning"
2014/6, Cubel, M.; Sanchez-Pages, S.: "Difference-form group contests"
2014/7, Del Rey, E.; Racionero, M.: "Choosing the type of income-contingent loan: risk-sharing versus risk-pooling"
2014/8, Torregrosa Hetland, S.: "A fiscal revolution? Progressivity in the Spanish tax system, 1960-1990"
2014/9, Piolatto, A.: "Itemised deductions: a device to reduce tax evasion"
2014/10, Costa, M.T.; García-Quevedo, J.; Segarra, A.: "Energy efficiency determinants: an empirical analysis of Spanish innovative firms"
2014/11, García-Quevedo, J.; Pellegrino, G.; Savona, M.: "Reviving demand-pull perspectives: the effect of demand uncertainty and stagnancy on R&D strategy"
2014/12, Calero, J.; Escardíbul, J.O.: "Barriers to non-formal professional training in Spain in periods of economic growth and crisis. An analysis with special attention to the effect of the previous human capital of workers"
2014/13, Cubel, M.; Sanchez-Pages, S.: "Gender differences and stereotypes in the beauty"
2014/14, Piolatto, A.; Schuett, F.: "Media competition and electoral politics"
2014/15, Montolio, D.; Trillas, F.; Trujillo-Baute, E.: "Regulatory environment and firm performance in EU telecommunications services"
2014/16, Lopez-Rodriguez, J.; Martinez, D.: "Beyond the R&D effects on innovation: the contribution of non-R&D activities to TFP growth in the EU"
2014/17, González-Val, R.: "Cross-sectional growth in US cities from 1990 to 2000"
2014/18, Vona, F.; Nicolli, F.: "Energy market liberalization and renewable energy policies in OECD countries"
2014/19, Curto-Grau, M.: "Voters' responsiveness to public employment policies"
2014/20, Duro, J.A.; Teixidó-Figueras, J.; Padilla, E.: "The causal factors of international inequality in co2 emissions per capita: a regression-based inequality decomposition analysis"
2014/21, Fleten, S.E.; Huisman, R.; Kilic, M.; Pennings, E.; Westgaard, S.: "Electricity futures prices: time varying sensitivity to fundamentals"
2014/22, Afcha, S.; García-Quevedo, J,: "The impact of R&D subsidies on R&D employment composition"
2014/23, Mir-Artigues, P.; del Río, P.: "Combining tariffs, investment subsidies and soft loans in a renewable electricity deployment policy"
2014/24, Romero-Jordán, D.; del Río, P.; Peñasco, C.: "Household electricity demand in Spanish regions. Public policy implications"
2014/25, Salinas, P.: "The effect of decentralization on educational outcomes: real autonomy matters!"
2014/26, Solé-Ollé, A.; Sorribas-Navarro, P.: "Does corruption erode trust in government? Evidence from a recent surge of local scandals in Spain"
2014/27, Costas-Pérez, E.: "Political corruption and voter turnout: mobilization or disaffection?"
2014/28, Cubel, M.; Nuevo-Chiquero, A.; Sanchez-Pages, S.; Vidal-Fernandez, M.: "Do personality traits affect productivity? Evidence from the LAB"
2014/29, Teresa Costa, M.T.; Trujillo-Baute, E.: "Retail price effects of feed-in tariff regulation"
2014/30, Kilic, M.; Trujillo-Baute, E.: "The stabilizing effect of hydro reservoir levels on intraday power prices under wind forecast errors"
2014/31, Costa-Campi, M.T.; Duch-Brown, N.: "The diffusion of patented oil and gas technology with environmental uses: a forward patent citation analysis"
2014/32, Ramos, R.; Sanromá, E.; Simón, H.: "Public-private sector wage differentials by type of contract: evidence from Spain"
2014/33, Backus, P.; Esteller-Moré, A.: "Is income redistribution a form of insurance, a public good or both?"
2014/34, Huisman, R.; Trujillo-Baute, E.: "Costs of power supply flexibility: the indirect impact of a Spanish policy change"
2014/35, Jerrim, J.; Choi, A.; Simancas Rodríguez, R.: "Two-sample two-stage least squares (TSTSLS) estimates of earnings mobility: how consistent are they?"
2014/36, Mantovani, A.; Tarola, O.; Vergari, C.: "Hedonic quality, social norms, and environmental campaigns"
2014/37, Ferraresi, M.; Galmarini, U.; Rizzo, L.: "Local infrastructures and externalities: Does the size matter?"
2014/38, Ferraresi, M.; Rizzo, L.; Zanardi, A.: "Policy outcomes of single and double-ballot elections"

2015

2015/1, Foremny, D.; Freier, R.; Moessinger, M-D.; Yeter, M.: "Overlapping political budget cycles in the legislative and the executive"
2015/2, Colombo, L.; Galmarini, U.: "Optimality and distortionary lobbying: regulating tobacco consumption"
2015/3, Pellegrino, G.: "Barriers to innovation: Can firm age help lower them?"
2015/4, Hémet, C.: "Diversity and employment prospects: neighbors matter!"
2015/5, Cubel, M.; Sanchez-Pages, S.: "An axiomatization of difference-form contest success functions"
2015/6, Choi, A.; Jerrim, J.: "The use (and misuse) of Pisa in guiding policy reform: the case of Spain"
2015/7, Durán-Cabré, J.M.; Esteller-Moré, A.; Salvadori, L.: "Empirical evidence on tax cooperation between sub-central administrations"
2015/8, Batalla-Bejerano, J.; Trujillo-Baute, E.: "Analysing the sensitivity of electricity system operational costs to deviations in supply and demand"
2015/9, Salvadori, L.: "Does tax enforcement counteract the negative effects of terrorism? A case study of the Basque Country"
2015/10, Montolio, D.; Planells-Struse, S.: "How time shapes crime: the temporal impacts of football matches on crime"
2015/11, Piolatto, A.: "Online booking and information: competition and welfare consequences of review aggregators"
2015/12, Boffa, F.; Pingali, V.; Sala, F.: "Strategic investment in merchant transmission: the impact of capacity utilization rules"
2015/13, Slemrod, J.: "Tax administration and tax systems"
2015/14, Arqué-Castells, P.; Cartaxo, R.M.; García-Quevedo, J.; Mira Godinho, M.: "How inventor royalty shares affect patenting and income in Portugal and Spain"
2015/15, Montolio, D.; Planells-Struse, S.: "Measuring the negative externalities of a private leisure activity: hooligans and pickpockets around the stadium"
2015/16, Batalla-Bejerano, J.; Costa-Campi, M.T.; Trujillo-Baute, E.: "Unexpected consequences of liberalisation: metering, losses, load profiles and cost settlement in Spain's electricity system"
2015/17, Batalla-Bejerano, J.; Trujillo-Baute, E.: "Impacts of intermittent renewable generation on electricity system costs"
2015/18, Costa-Campi, M.T.; Paniagua, J.; Trujillo-Baute, E.: "Are energy market integrations a green light for FDI?"
2015/19, Jofre-Monseny, J.; Sánchez-Vidal, M.; Viladecans-Marsal, E.: "Big plant closures and agglomeration economies"
2015/20, Garcia-López, M.A.; Hémet, C.; Viladecans-Marsal, E.: "How does transportation shape intrametropolitan growth? An answer from the regional express rail"
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2019

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