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The role of information for energy efficiency in the residential sector

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ABSTRACT

In spite of the large potential and existing efforts to foster energy efficiency in the residential sector, much remains to be achieved. This may be partially due to the many barriers and market failures faced by energy efficiency, which are even greater in this sector. In particular, informational failures seem to be pervasive and relevant in this area. Addressing these issues requires specific policy instruments and strategies. This paper reviews the empirical evidence on the effectiveness of such instruments, focusing on energy certificates, feedback programs, and energy audits. Results show that energy certificates and feedback programs can be effective, but only if they are carefully designed, whereas the evidence about the effectiveness of energy audits is mixed. In addition, the paper points out the large potential for new instruments as well as combinations of existing ones.

1. Introduction

Many international institutions (European Commission, 2011; IEA, 2013; OECD, 2003) suggest that energy efficiency is the best tool to keep energy demand under control and key to facilitate the transition towards a low-carbon future. This consensus extends to the key role of the residential sector in this strategy, in particular buildings, given that it presents the highest cost-efficient potential for mitigation of CO_2 emissions.[1]

Therefore, many governments have made it a priority to improve energy efficiency levels in this sector and they are seeking to promote this through several different policies. These policies have generally consisted in building codes and standards, and also price instruments such as taxes and, more frequently, subsidies (Markandya et al., 2015). However, in spite of the significant efforts and resources devoted to these policies, the results have not been as expected. In Europe, for instance, a comparatively intense use of EU and national policies to promote energy efficiency has coexisted with a growing energy demand in the residential sector, with an apparently large unexploited energy saving potential (European Parliament, 2014). Fig. 1 shows for example how energy consumption per dwelling per squared meter has been quite stable in many European countries since the beginning of this century.

Indeed, a close look at the situation highlights the existence of several barriers associated to energy efficiency measures in the residential sector and which help explain, at least in part, the "Energy Efficiency Paradox", understood as the divergence between the cost effective potential identified by energy–economic models and the levels of adoption observed in practice (Jaffe and Stavins, 1994). Optimal energy efficiency levels are rarely met in a sector characterized by dualities in stock (existing vs. new buildings), in the use of buildings (commercial vs. residential) and in the preferences of the agents that participate (owners vs. renters), and this is due to many barriers. Hidden or transaction costs (not accounted by models, but real) are also pervasive in this sector. The consequence is that energy efficiency does not reach levels corresponding to the "win–win" opportunities that models have usually identified in this market, that is, that the opportunities identified by models may not be consistent with the willingness to pay (WTP)[2] expressed by consumers.

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[1] Currently, buildings consume one third of global final energy, and the same share of carbon emissions is directly or indirectly related to this sector (IEA, 2013). In the EU, houses, offices, shops and other buildings consume 40% of primary energy and are responsible for 36% of greenhouse gas emissions (European Commission, 2013). Moreover, these figures are expected to grow due to the increase in building stocks and energy intensity in emerging countries such as China or India.

[2] In the last few years a significant amount of empirical research has tried to estimate the WTP for insulation measures or efficient cooling or heating systems, usually concluding that WTP was positive. Banfi et al. (2008) reported positive WTP for a hypothetical change of insulation and ventilation systems for apartment renters and house owners in Switzerland, although the analysis of the determinants was limited because they could not include socioeconomic variables. Also for Switzerland, Alberini et al. (2013) found a positive WTP for owners of semi-detached and detached houses, even though this was only for those owners who expected increases in energy prices or those who were convinced of the relevance of house retrofitting programs within climate policies. Similar results have been obtained for Germany (Achtnicht, 2011), South Korea (Kwak et al., 2010) and Hong Kong (Chau et al., 2010).

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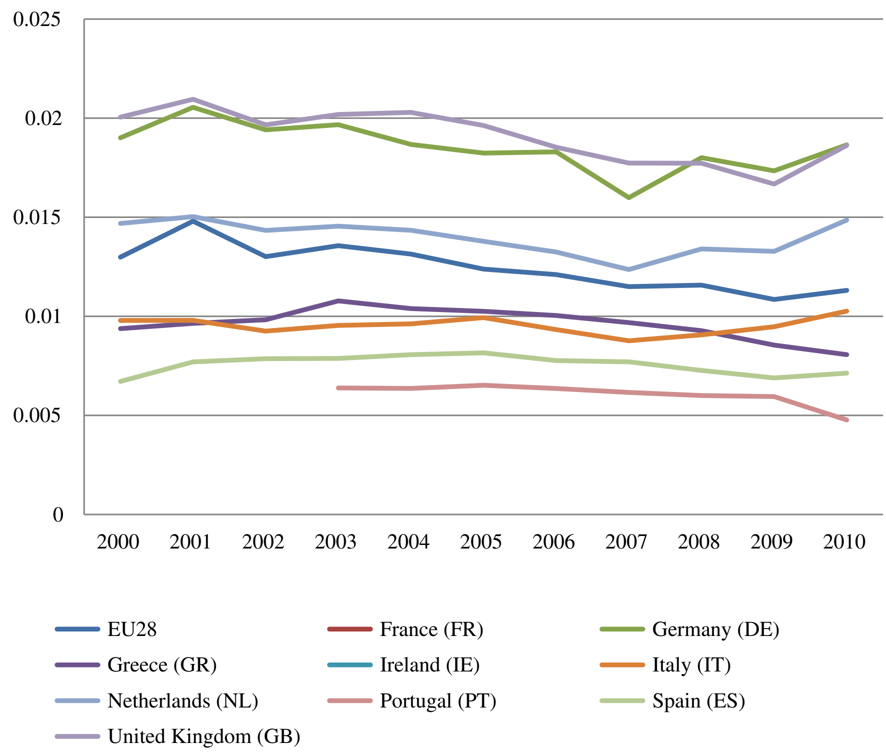

Fig. 1. Residential final energy consumption in selected countries (Toe/dwelling/m^2). Source: Enerdata.

Until recently, the standard framework for dealing with the Energy Efficiency Paradox was based on the traditional analysis of market failures. This resulted in public interventions through economic (price or quantity) instruments and standards. For example, energy prices usually do not internalize environmental (or other) externalities derived from the use of energy and this, in turn, determines excessive pollutant levels or a higher than optimal energy use (Gillingham et al., 2009). If the price of energy does not correspond to the real marginal cost, the adoption of energy efficiency measures is disincentivized. This market failure demands public intervention to take prices to their right level, including social costs.

But the use of conventional regulatory instruments has shown many limitations. For example, Iwaro and Mwasha (2010) collect information about 60 countries in Africa, Latin America and Middle East, and argue that, in spite of the recent growing use of energy standards in these countries, most of these standards are far from the ones set in developed countries. But even in advanced economies the effects of building codes on energy consumption seem to be reduced: Levinson (2014), for instance, uses three different approaches to test whether California's building codes met their objectives in terms of energy savings. He compares energy consumption from 8.700 homes in 2003 and 11.000 in 2009 constructed under different standards, controlling for several factors, such as size, ownership status and weather. Aroonruengsawat et al. (2012) additionally control for building code intensity, electricity and gas prices and the share of new construction, to compare per capital electricity consumption in 48 U.S. states; while Jacobsen and Kotchen (2013) compare billing data on electricity and gas consumption in more than 60.000 dwellings in Florida before and after an increase in the code's stringency was produced, controlling for the observable characteristics of each residence and weather. A common finding in the previous papers is the limited effect in energy consumption of regulatory instruments. The effectiveness of price instruments, such as energy taxes, has also been constrained by the low elasticity of energy demand, as showed by Gillingham et al. (2009) or Ryan et al. (2011) in this area. Finally, although subsidies could be very effective given that investment cost is one of the most relevant factors for consumers (Mourato et al., 2004; Nair et al., 2010a), making unrestricted use of them typically results in inefficiencies due to high fiscal cost and the free-riding effect.[3]

The evidence of the reduced levels of energy efficiency attained through conventional policies raises the question of whether the traditional approach, in which consumers are assumed to have perfect information and make rational decisions, corresponds to real energy efficiency residential markets[4] (Stern et al., 1987). Probably the preceding analysis is too limited and requires relaxing these assumptions and incorporating other elements such as informational and behavioral failures (Allcott and Mullainathan, 2010; Shogren and Taylor, 2008). This in turn has opened the way to new instruments that address these failures[5] (Tietenberg, 2009) as well as to the sizeable empirical research presented in this paper.

In particular, researchers have focused on information programs as well as on behavioral interventions[6] as ways to close the Energy Efficiency Paradox. Indeed, informational instruments have become increasingly popular as regulators may use them to mitigate the negative effects generated by both, informational and behavioral failures. Of course, the type of information instruments chosen depends on the informational or behavioral problems targeted (see the next Section): i) Certificates or labels that show the energy efficiency of a product; ii) Feedback to customers, which can be channeled through smart meters that show real-time energy consumption or bills with comparative information about similar or representative households; and iii) Energy

[3] Banfi et al. (2008) and Grösche and Vance (2009), for example, observed that for a very high share of households in Switzerland and Germany, the WTP for certain energy efficiency measures exceeded the investment cost.

[4] As already pointed out for many sectors by Kahneman (2011), Mullainathan and Thaler (2000) or Simon (1955).

[5] Although in some cases the intervention may respond to paternalism rather than to efficiency concerns, which of course raises some ethical questions. We address this point later in the paper.

[6] These interventions try to induce more efficient behaviors through “nudges” such as feedback, commitments, goal setting, social comparisons, normative messages, or manipulation of default options (Brown et al., 2013; Croson and Treich, 2014; Ehrhardt-Martinez et al., 2010). Frederiks et al. (2015) present examples of how to carry out these policy interventions.

Table 1
Possible explanations for the Energy Efficiency Paradox.

	Informational failures	Behavioral failures	Potential informational instruments
Lower-than-efficient energy prices			
Slowness of technological diffusion			
Capital markets imperfections			
Heterogeneity of consumers			
Asymmetric and/or incomplete information	X		Certificates Feedback Audits
Principal-agent[a]	X		Certificates
Hidden costs	X		
Transaction costs	X		Certificates Feedback Audits
Uncertainty	X		Certificates Audits
Decision-making heuristics and biases		X	Certificates Feedback Audits

Source: The authors.
[a] The principal-agent problem is created partly by some of the other explanations cited in the table. However, since it represents a particular case of market barrier that has been deeply analyzed in the literature, we considered convenient to present it separately.

audits with tailored information about specific measures households may adopt to reduce consumption.

Up to now, most empirical evidence had focused on the assessment of the cost-efficiency of conventional policies (Gillingham et al., 2006; Ürge-Vorsatz and Novikova, 2008) with ex-ante models that estimated and compared the expected results of each instrument. Recently, though, there have been many advances in the empirical analysis of energy efficiency in the residential sector by using ex-post data and also by progressing in the study of consumer behavior. The widespread application of energy efficiency policies has provided large databases that allow estimating the real impacts of these policies, and the determinants of the agents' decisions, thus improving our understanding of household behavior. In addition, experimental methodologies with rigorous design and the use of large-scale random samples are extensively being employed to study novel aspects of energy efficiency in buildings.

This article provides a comprehensive update on the knowledge of the performance of energy efficiency policies in the residential sector, with a particular emphasis on informational instruments. We focus on the residential sector because here informational and behavioral problems are much more frequent: households are not typically governed by cost-minimizing rules or "rational" decision making, and do not have easy access to information. This leads to a situation with many market barriers for energy efficiency in buildings, vehicles or appliances, and which makes this sector an interesting field of analysis. However, given that the development of these informational instruments has run parallel to that of other markets, such as commercial buildings, we will also refer to them in order to draw analogies and to provide a more integrated view of the new role that information will have to play in sectors presenting substantial barriers for conventional instruments. The paper's contribution rests on being the first attempt, to the best of our knowledge, at compiling all the empirical evidence about informational instruments applied to energy efficiency in the residential sector. Second, and based on this empirical evidence, it provides some insights about the pertinence of the different instruments in terms of cost-effectiveness, and also on the attractiveness of integrated policy packages.

We begin by describing the way in which informational and behavioral failures contribute to the Energy Efficiency Paradox (Section 2), and then move on to reviewing the empirical evidence on the performance of instruments designed to address these problems: energy labels and certificates, smart meters, bills with comparative information, and energy audits (Section 3). The review shows that the impact of informational instruments on energy efficiency in dwellings is positive, although variable. The new approaches identified also show the potential for clearer results in the near future, highlight the difficulties of using only conventional instruments, and pave the way for the design of new, broad, integrated policy packages for energy efficiency in the residential sector in which informational instruments play a big part. In Section 4 we provide some policy guidelines, before concluding and considering future research needs in the final section.

2. The role of information and behavior in the Energy Efficiency Paradox

As mentioned earlier, informational and behavioral failures may play a very significant role in explaining the Energy Efficiency Paradox, in particular in the residential sector. In this section we enumerate and describe the aspects related with household informational and behavioral failures that can be potentially addressed using informational instruments.

In Table 1 we start from a classical account of the possible explanations for the Energy Efficiency Paradox (from Linares and Labandeira, 2010) and mark those that correspond to informational or behavioral failures to show the relevance of these problems in this context.[7] We also include in the table the informational instruments that might address these problems. In this sense, a single instrument may cover simultaneously several problems: for example, certificates may be used to provide information that was so far incomplete, or to alleviate an information asymmetry, or to create a social norm; energy audits may counter bounded rationality (a behavioral failure) or provide additional information as feedback instruments. The subsequent literature review is intended to identify the aspects better covered by such instruments, and the problems for which they may be more effective.

2.1. Informational failures

The fact that consumers do not observe the amount of electricity consumed by a washing machine during a washing cycle or the energy required by a house to maintain the standard temperature, makes energy efficiency an intangible and secondary characteristic of energy goods. Therefore the nature of energy efficiency itself creates several problems related to information, which is frequently incomplete,

[7] It should be remarked that the explanations included in the table correspond to the definition of the Energy Efficiency Paradox we use in the paper. Other definitions, such as the one that restricts the paradox to the observation that consumers neglect apparently cost-effective opportunities at current energy prices, would not include lower-than-efficient energy prices as a possible explanation.

generally asymmetric, and almost always costly to obtain. As a result, consumers value this unobservable characteristic less and tend to not include it among their preferences when buying a new product and this, in turn, prevents them from managing their energy use in the right way.

Determining the energy efficiency of a product is a complex task, generally restricted to experts, which also creates a situation of asymmetric information. Some agents have all the information, whereas for others accessing this information is difficult and costly. These asymmetric information problems are related with the principal-agent or split incentives problems generated in those situations when the incentives for the different agents involved in a transaction are not aligned. Since they are not able to appropriate the returns of the investments in energy efficiency, this leads them to an inefficient allocation of resources. The characteristic duality of the residential sector for rental dwellings (owners and tenants, buyers and sellers, or homeowners and building contractors) particularly affects energy efficiency decisions. If the homeowner does not live there, or if the tenant does not pay directly utility costs, the energy use may be higher given the lack of the right price signal (Maruejols and Young, 2011). The benefits of energy savings do not accrue to the owner who, nonetheless, must pay for the new investments. As a result, investments in energy efficiency are lower than optimal.

Over the last decade, a great effort has been made to identify and quantify these distortions, in particular the principal-agent problem. In absence of specific databases, some researchers have used investment in energy efficiency and the use of energy for heating or cooling (from household surveys) and have applied binary choice models to estimate the effect of ownership. This is the case, for example, of Brechling and Smith (1994), who identified ownership as the single socioeconomic factor that, together with the rest of structural characteristics of the dwelling, had a significant effect on the probability of investing in energy efficiency. Similar results were obtained for Ireland by Scott (1997). Also, Schleich and Gruber (2008), using a sample of 19 sub-sectors in the commercial and residential sectors in Germany, identified principal-agent and imperfect information problems as the most important barriers to achieving optimal levels of energy efficiency.

The availability of specific surveys for energy use has permitted a wider range of approaches and applied empirical techniques. With data from the Residential Energy Consumption Survey and the American Housing Survey, Levinson and Niemann (2004) analyzed the incidence of the principal-agent problem on the temperature set by households in winter. Using probit and OLS regression models, they revealed a negative effect when contracts included heating expenses in the rental cost. These results were confirmed for Canada by Maruejols and Young (2011) who, using data from the *Household Energy Use* survey, showed that multi-family buildings where households do not directly pay for heating were more likely to set higher temperatures.

More recently, Gillingham et al. (2012), using a large sample of households from the *California Statewide Residential Appliance Saturation Study*, showed that households occupied by owners had a 20% higher probability of featuring insulation in roofs and attics, while households whose tenants directly paid for energy had a 16% higher probability of changing the temperature set during the night. With a linear probability model and data from the US, Davis (2012) also confirmed the relevance of the principal-agent problem for buying efficient appliances and lighting systems because tenants who did not directly pay for electricity had a lower probability of buying this type of equipment.

Finally, the IEA (2007) has tried to approximately quantify the amount of energy affected by this problem, using as case studies the residential, commercial and end-use sectors in Japan, U.S., the Netherlands, Norway and Australia. They found significant evidence of principal-agent problems: in particular 41% of dwellings in the Netherlands corresponded to homes where the end user paid the energy bill but did not choose technology, whereas 31.4% of the energy consumed in the residential sector in the U.S. was affected by principal-agent situations.

There are other informational failures that have been less studied in this sector: uncertainty, hidden costs and transaction costs. Consumers cannot assess how reliable the information provided by the expert is, which makes them uncertain about adopting energy efficiency measures. This uncertainty is further compounded by the variability of future energy prices and changing regulatory environments that, together with the preceding, makes it harder to estimate the economic return of investments. Given that these investments are irreversible, uncertainty clearly deters them. Moreover, uncertain scenarios give rise to specific behavioral failures (see Table 1 in Appendix A).

Hidden costs may also be included among the information barriers, but in this case from the modelers' side: these are real costs suffered by consumers, but not always accounted for by modelers. Therefore, they are frequently not incorporated in cost-benefit analysis, thus leading to an overestimation of net benefits. Authors such as, Jaffe et al. (2004) suggest that including these costs reduces the Energy Efficiency Paradox.

Finally transaction costs, associated to obtaining information or of making an economic transaction,[8] create frictions in the market that may result in non-optimal outcomes (Sorrell et al., 2004). These costs may be very relevant in the residential sector, since households usually experience them in a higher proportion than other sectors, and independently or combined with behavioral failures (see the following section) they typically result in lower investment levels in energy efficiency.

2.2. Behavioral failures

They are a source of inefficiencies that is strongly related with previous informational failures, and which can also be mitigated with informational instruments. The hypothesis formulated by behavioral economics on the systematic deviation of consumers from the perfect rationality[9] assumed by neoclassical economics has become more and more relevant in assessing public policies during the last few years (DellaVigna, 2009; Mullainathan and Thaler, 2000). Following Shogren and Taylor (2008), we employ the term “behavioral failures” for all those situations in which the consumer does not behave according to rational choice theory. There are many behavioral failures and also many typologies, some of which depend on the theory considered to explain these failures, the major ones being Prospect Theory (Kahneman and Tversky, 1979); Bounded Rationality (Simon, 1955); and Regret Theory (Loomes and Sugden, 1982). Table A1 in the Appendix A summarizes the most relevant failures described in the literature.

Allcott and Mullainathan (2010), Dyner and Franco (2004), Gillingham et al. (2009), Shogren and Taylor (2008) or Tietenberg (2009) have already pointed out the relevant role that this approach may play in understanding the Energy Efficiency Paradox. The decision to buy or rent a house involves many complex choices. On the one hand, time and cognitive limitations prevent consumers from correctly estimating the future energy performance of a house. On the other hand, there are many attributes to be considered (location, size, age, price, style, garage, energy efficiency, etc.). As a consequence, consumers may apply heuristic rules that simplify their choices, such as considering only the more salient or familiar features or the default option; excluding energy efficiency from the factors to take into account. In practice, this is equivalent to the case that consumers do not value energy

[8] It should be noted that here we are following the Coasian idea of transaction costs. There are broader definitions of transaction costs, such as the one proposed by Oliver Williamson (1981), and which includes other issues such as limited rationality or opportunism into it. Here we have preferred to keep these concepts separated (although related) for the sake of simplicity.

[9] Readers interested in this topic may refer to the recent books of Kahneman (2011) or Thaler and Sunstein (2008) that, although directed to the general public, compile most of the relevant academic literature and present it in a clear way.

efficiency. Additionally, uncertainty about future energy prices and about the results from novel technologies may increase consumer risk aversion or reference dependence ("status quo" bias), leading to lower than expected energy efficiency investment.

One reason for these behavioral failures is the lack of knowledge about energy costs, although they represent a significant part of household income. Brounen et al. (2013) illustrated this possibility with a survey on 1.721 households in the Netherlands, in which around 50% of the respondents did not know their energy expenses (the average energy bill was 222 Euro, 8% of income). Nair et al. (2010b) showed that this issue also had negative effects on energy efficiency in Swedish households, as families considering that their energy expenses were high would be more active in this area.

Although DellaVigna (2009) and Gillingham and Palmer (2013) have reviewed the empirical evidence of this type of behavioral failures in several fields, the consideration of energy efficiency in the residential sector has been quite limited so far. Qiu et al. (2014), Greene (2011), Erdem et al. (2010) and Farsi (2010) empirically analyze time and risk preferences and find evidences of the effects of these factors on household energy efficiency adoption.

It is difficult to robustly measure the behavior of consumers in a market as complex as energy efficiency in dwellings and considerable analysis is still required to settle very relevant questions, such as how these failures affect energy efficiency, how behavioral and market failures relate, or whether they can be corrected through learning or repetition (Shogren and Taylor, 2008).[10] However, the use of novel experimental techniques represents an interesting tool to increase the current knowledge about these aspects.

3. A review of the performance of information-based energy efficiency policies

Acknowledging the relevance of the informational and behavioral failures in the Energy Efficiency Paradox has promoted the design of policies that attempt to provide better information to consumers and enable them to avoid non-rational behaviors and adopt the most efficient decisions. For example, the EU Energy Efficiency Directive (2012/27/EU) focuses on demand management programs for households as an alternative to price instruments. Indeed information-based instruments, such as energy certificates, energy audits, or information of energy use, are not only less costly to implement but may be also very effective in achieving energy efficiency (Allcott and Mullainathan, 2010; Ayres et al., 2012).

Of course, a first issue to raise here is whether public intervention is warranted in all cases. Addressing informational problems, which generally constitute market failures, is difficult to contest. But, what about behavioral failures? As mentioned at the beginning of this section, many behavioral failures are strongly linked to informational failures and barriers. For instance, those situations where consumers use heuristic rules to simplify complex and time-consuming decisions may be explained by incomplete and asymmetric information. In such cases, public intervention is justified by the existence of informational market failures, and informational instruments represent an appropriated tool to counter both problems. However, there are other behavioral failures (for example decisions based on Regret or Prospect theory, or status-quo effects) that do not properly constitute or originate from market failures. In these cases, public intervention may be considered a form of paternalism, which can be argued against on ethical grounds. Although this discussion is outside the scope of this paper, insights of this debate can be found in Tietenberg (2009) and Stavins et al. (2013).

As before, now we proceed to review the existing empirical evidence on the performance of several information-based instruments.

3.1. Energy certificates and labels

Energy certificates or label programs have quickly expanded over the last years, particularly in the building sector but also for residential appliances and cars. These certificates or labels use different colors or symbols to show different energy efficiency levels that are usually determined from the structural characteristics of the products and their importance in its energy performance. Certificates vary depending on their public or private character; on the typology of the goods targeted (residential or commercial); and on their mandatory or voluntary nature. In some countries, such as the U.S., energy certificates are voluntary and only used for very efficient products.[11] In the EU energy certificates are mandatory for appliances, vehicles and buildings, and all products are classified based on their energy efficiency level (in a scale from A, most efficient, to G, least efficient).[12] Furthermore, in the residential and commercial buildings, the owner must show the certificate to the renters or buyers every time she wants to rent or sell the dwelling.

Certificates are basically designed to help consumers to take efficient decisions through the provision of direct, reliable and costless information that otherwise would not be available. Thus energy certificates or labels target several informational failures at the same time: incomplete and/or asymmetric information, transaction costs and uncertainty, and reduce those behavioral failures generated by informational failures and barriers such as limited attention, aversion to uncertainty, etc. Energy certificates or labels can also reduce principal-agent problems. When an agent wants to rent or buy a dwelling, energy certificates or labels give ex ante information about future energy costs that may influence the agent's choice. This situation can further create indirect incentives for owners or builders to invest in energy efficiency.

The diffusion of this policy tool has been accompanied by a strong development of the empirical research assessing their impact on consumer decisions and on the price of the residential or commercial goods. Some studies have also looked at the effectiveness of the institutional and design aspects of these instruments: Mlecnik et al. (2010), for example, surveyed experts in 25 countries to identify the barriers and elements capable of improving the diffusion of certificates, such as increasing their relative advantages and their visibility and transparency for consumers, or reducing complexity and facilitating the transfer of knowledge. Bull (2012) highlighted the importance of the frame in which information is offered, using a choice experiment to show the importance of informing about the monetary value of the energy savings, or of the economic losses incurred instead of the potential benefits. Banerjee and Solomon (2003) used existing studies and reports to compare the effects on consumers and manufacturers of five (private and public) energy-labeling programs for appliances and electricity in the U.S. Their results showed that public systems were more successful and stressed the importance of the government in providing credibility and stability to these programs. The IEA (2010) also confirmed that the effect of a mandatory system is higher because more goods are identified, but it warned that public costs increase with such a system.

The market has not yet been able to generate enough data to estimate the effect of introducing certificates on energy demand, neither at the aggregate nor at the disaggregate level. However, it is possible to estimate the direct effect of energy certificates on the decisions of the agents. In the case of buildings the value of certificates can be

[10] The heterogeneity of households should also be taken into account, as their behavior may depend on cultural or ideological factors. For example, many studies have reported empirical evidence on the importance of concern for the environment in energy use and energy efficiency of residential consumers (Costa and Kahn, 2010; Di Maria and Lazarova, 2008; Kahn and Vaughn, 2009; Kotchen and Moore, 2007; Lange et al., 2014; Ramos et al., 2015). Another source of heterogeneity is the different use of home appliances (Houde, 2014a).

[11] In the US there are two voluntary systems for energy certificates: the Energy Star program for appliances, managed by the Environmental Protection Agency (EPA); and the LEED program for buildings.

[12] These systems are regulated by Directives 2012/27/EU, 1999/94/CE and 1992/75/CEE.

obtained with the use of hedonic methods (Rosen, 1974), employing econometric models that control thermal conditions of the unit as well as other hedonic characteristics (vintage, location, etc.) to determine the WTP of buyers or renters. However, results from the hedonic price model can be biased if the price function suffers from omitted variables bias. Another limitation associated with this model is the presence of correlation between the product's attributes.

Table 2 summarizes the major empirical evidence on WTP for certificates in buildings. A first group of studies were carried out in the commercial sector in the U.S., with the use of information compiled in the CoStar database (Eichholtz et al., 2010, 2013; Fuerst and McAllister, 2011a, 2011c; Reichardt et al., 2012; Wiley et al., 2010). These results are of major importance for our analysis since the commercial building market and the residential building market share many characteristics. All these studies estimated that energy-efficient buildings (certified with LEED or EnergyStar labels) obtained higher rents or selling prices than others with the same characteristics but without certificate. Although with smaller databases, Das et al. (2011) and Bloom et al. (2011) confirmed these results for San Francisco, Washington DC and Colorado. Interestingly, the results of these studies also show a positive relation between certification and the occupation rate in commercial buildings, in addition to the fact that part of the WTP could be attributed not only to the expected energy use but also to unobservable factors such as the environmental attitude of the consumers or the reputational effect (Eichholtz et al., 2013; Muehlegger and Gallagher, 2011).

Similar studies have been carried out in other countries with varying results. Fuerst and McAllister (2011b) did not find any effect for the commercial sector in the UK, although Chegut et al. (2013) did find it for London. Kok and Jennen (2012) also found a positive effect for the commercial sector in the Netherlands, showing that inefficient commercial buildings (those with a D or lower grade) were rented at a 6% discount. As for the residential sector, results also overwhelmingly point to a positive WTP for certified homes. In Europe Brounen and Kok (2011) studied the response of Dutch households to the EU energy certificate system and found that homes certified as A, B or C achieved premiums of 3.6% in their selling price as compared to others. Högberg (2013) used the information on standard energy use included in the certificate to determine if energy use is capitalized in the selling price of homes in Sweden. Using a sample of more than 1.000 homes in Stockholm they also confirmed that there is a positive relation between energy use and selling price. Hyland et al. (2013), in turn, used a panel with data for selling and renting prices from the website of a real estate company from 2008 to 2012 in Ireland. Following the methodology of Brounen and Kok (2011) they found that an “A home” was sold at 9.3% more than a “D home”, and a “B home” was sold at 5.2% more than a “D home”, whereas a “F or G home” had a 10.6% discount as compared to a “D home”. The Irish study also found that the WTP was 1.8% more for an “A home”, and 3.9% more for a “D home”. Cajias and Piazolo (2013) confirmed these results for Germany between 2008 and 2010.

There have also been studies for Asia, with heterogeneous results. Deng et al. (2012) used a hedonic model with two stages to control for the location effect of apartment buildings in Singapore. In their results the value of the certificate used (Green Mark) increases the selling price of homes by 4%. However, Yoshida and Sugiura (2011) found that, if the hedonic model is controlled for vintage and quality of the building, then the energy certificates used in Tokyo could even have a negative effect on the price of the home due to the higher cost of the efficient systems or perhaps rebound in energy consumption. Indeed, Newsham et al. (2009) found that LEED buildings decrease their energy consumption by 18–39% on average, even though 28–35% of them had increased

Table 2
Empirical research on the value of certificates or labels for energy products.

Study	Sector	Results: WTP	
		Rent (effective)	Sales
Eichholtz et al. (2010)	Commercial U.S.	3% (7%)	16%
Eichholtz et al. (2013)	Commercial U.S.	3% (8%)	13%
Wiley et al. (2010)	Commercial U.S.	7–9% Energy Star 15–17% LEED	30$/f2 Energy Star 130$/f2 LEED
Fuerst and McAllister (2011a)	Commercial U.S.	4–5%	25%
Fuerst and McAllister (2011c)	Commercial U.S.	3% Energy Star 5% LEED 9% Energy Star + LEED.	18% Energy Star 25% LEED 28–29% Energy Star + LEED.
Reichardt et al. (2012)	Commercial U.S.	2.5% Energy Star 2.9% LEED.	
Das et al. (2011)	Commercial U.S.	Positive and dynamic	
Bloom et al. (2011)	Commercial U.S.		8.66$/f2
Kok and Jennen (2012)	Commercial Netherlands	−6%	
Fuerst and McAllister (2011b)	Commercial UK	Not significant	Not significant
Chegut et al. (2013)	Commercial London	19.7%	14.7%
Brounen and Kok (2011)	Residential Netherlands		3.6%
Högberg (2013)	Residential Sweden		Positive WTP
Hyland et al. (2013)	Residential Ireland	A: 1.8% B: 3.9% C: not significant E: −1.9% F/G: −3.2%	A: 9.3% B: 5.2% C: 1.7% E: not significant F/G: −10.6%.
Cajias and Piazolo (2013)	Residential Germany	Total returns: B: 2.27% C: 2.34% D: 2.69% E/F: not significant G: reference	
Yoshida and Sugiura (2011)	Residential Tokyo		Negative
Deng et al. (2012)	Residential Singapore		4%
Zheng et al. (2012)	Residential Beijing	Negative	Negative
Wall et al. (2013)	Residential U.S.		Positive for houses built 1996–2005. Not significant for newer houses. Values reach up to 20%
Kahn and Kok (2014)	Residential California		9%.

Source: The authors.

their energy consumption. Zheng et al. (2012) studied the value of buildings that were publicized as "green", showing that this characteristic had a positive effect on the bidding price but it was not materialized in the real selling price, which could be explained by a lack of veracity in the information provided.

Finally, two studies have dealt with this matter for the residential sector of the U.S. Wall et al. (2013) indicated that the energy certificate is only effective for the price of old homes, but not for new ones (may be because of the different marginal energy savings, which can be lower in new homes) in Austin, Portland and the research triangle area of North Carolina. However, Kahn and Kok (2014) found a WTP of 9% of the selling price for certified homes in California.

This same outcome for energy certificates in buildings has been replicated in other areas of residential energy use. In particular, two papers have estimated a positive WTP for energy certificates for private vehicles. Galarraga et al. (2014) found that efficient cars (with an A or B certificate) were sold with a premium of between 2.1% and 9% in Spain. Alberini et al. (2014) used matching estimators and a regression discontinuity design to estimate the value of A labels in Switzerland, showing that the price of an A label ranged between 5% and 6–11% for each methodology.

Estimation of WTP from stated preferences for appliances has been also widespread. Some examples are Sammer and Wüstenhagen (2006), for washing machines in Switzerland; Wallander (2008), who combines hedonic pricing with discrete choice models for EnergyStar-certified washing machines in the US; Shen and Saijo (2009), with a latent class approach to analyze the case of air conditioners and refrigerators with the China Energy Efficiency Lab in Shanghai; Ward et al. (2011), with the same approach for refrigerators in the U.S.; Galarraga et al. (2011), with the use of hedonic pricing to estimate the WTP for efficient dishwashers in Spain; and Newell and Siikamäki (2014), for EnergyStar water heaters in the U.S. Recently, Houde (2014a) used a natural experiment (the change in the requirements for refrigerator certificates in the U.S.) to estimate the treatment effect of certificates. He obtained three types of answers with a structural model: agents who value the EnergyStar label even more than the energy savings implied, agents who only value the information about the energy use, and agents who do not value any of these characteristics.

Some studies about appliances have pointed out the need to tailor the information included on the label to the specific circumstances of consumers. For example, Davis and Metcalf (2014) evaluated the quality of the information provided by the mandatory labels for appliances used in the U.S. They wondered whether state-specific labels tailored to the state of residence of each participant were efficient, and thus they carried out an online choice experiment where participants had to choose to hypothetically purchase one of three air conditioners. The control group was shown an official energy label providing consumers with information on the expected annual energy cost according to national energy prices and use, while in the treatment group an alternative label was shown with information on expected annual energy costs based on state energy prices and uses. Their results showed that state-specific labels led to significantly better choices, although they also indicate that consumers did not fully understand the information displayed in the label.

The informational value of an energy certificate or label could also be substituted by an informal procedure. Allcott and Sweeney (2015) developed a natural experiment in collaboration with an appliance retailer, in which 20.000 customers who bought water heaters were offered two levels of information: some were told about the energy efficiency of the heaters, while others were not. Their results show that this information had a limited effect, although this may be due to the fact that only explicitly interested customers received information. Another explanation, of course, would be the lower level of trust that customers may have placed on the sales agents (as compared to a well-established certificate).

Allcott and Taubinsky (2015) also run two randomized control trials to estimate the impact of information on the decision to buy compact fluorescent bulbs. The first was a choice experiment, through Internet, that estimated the effect of randomly providing information of the energy cost and lifetime of the product. The second provided information through a sales agent who randomly intercepted customers in a shopping mall and asked them to fill in a questionnaire. Results show that information was significant only in the first experiment.

Another way to offer information about the energy performance of a product is to express it in monetary terms. In the 1980s some experiments measured the effect of informing about the energy costs of appliances, with a survey on these studies showing mixed results (Kaenzig and Wüstenhagen, 2009). The recent introduction of energy certificates in the U.S. and the EU has spurred renewed academic interest in this issue. Deutsch (2010) carried out an online field experiment in which he attempted to estimate the effect of providing information about the life-cycle cost of washing machines sold by a German online website. In this experiment consumers were randomly assigned to two groups, one receiving the life-cycle cost information and the other not receiving it. Results show that this information reduced the energy use of the washing machines sold by 0.8%.

And, of course, monetary costs can be added to energy performance labels. Kallbekken et al. (2013) ran an experiment in Norway in which they provided information about energy costs through an experimental energy label (developed by the seller) showing the operational cost over the lifetime of dryers and refrigerators, which was additional to the information on the mandatory energy label. They also trained sales agents to inform customers about this matter. Just like Allcott and Sweeney (2015), they found no significant effect of this additional information in the case of refrigerators, but they did find a positive and significant one for dryers (although there was no effect for the energy label alone).

Of course the results of all these studies cannot be compared directly. The WTP for a certificate would vary depending on, for example, the energy consumption of a typical building, or the use of vehicles in a specific region. The certification system or energy prices may also influence the WTP for them. Marginal energy savings (which will depend on different standards for energy use in buildings, vehicles or appliances) will also result in different WTP for certificates. Finally, comparing building with appliance or vehicle certificates is also problematic. Yet, beyond those differences, there is clear empirical evidence that consumers positively value energy certificates or labels. Indeed, there is evidence that they value the certificate in some cases independently of the higher energy efficiency it represents.

The evidence also points to some characteristics of the design that seem to increase the effectiveness of this tool: reliability that might be provided by a public scheme; mandatory systems that increase the size of the effect; or framing the information in terms of monetary costs rather than in CO_2 emissions or energy units. It is also important to include a monitoring procedure to ensure the correct implementation of the legislation.

3.2. Feedback

Over the last few decades, information on the household use of energy (feedback) has become an important instrument to achieve energy savings. If consumers are aware of the way they use energy and of its cost, they should be interested in reducing their energy consumption. As it was mentioned before, energy consumption is intangible and consumers can hardly know how their daily habits are translated in energy consumption. Thus, feedback is an essential tool to mitigate informational failures such as incomplete information and behavioral failures as those generated by wrong beliefs about energy consumption. Of course, this strategy could also create wrong incentives (the so-called boomerang effect): if consumers find that they use or spend less than expected, they might even increase their consumption. But feedback can also work as a good complement for conventional instruments since it can augment their effectiveness by increasing the elasticity of demand. For example, Jessoe and Rapson (2014) observed in a field experiment that the effect of a price change was higher in households that received real-time information (through a smart meter) than it was in the control group.

Abrahamse et al. (2005) reviewed 38 studies carried out between 1977 and 2004 to assess the effectiveness of feedback programs (through meters in 13 experiments). Results showed that this information can sometimes produce energy savings and that its effectiveness increases as does the frequency in which the information is received. That review also included the results of three experiments providing information on a comparative basis: in two of them differences were insignificant, while the third one did produce some energy savings in gas and electricity due to the exchange of information between groups of neighbors in the Netherlands (Staats et al., 2004).

Darby (2006) also reviewed almost 30 studies in the US, Canada, Scandinavia, the Netherlands and the UK, and concluded that immediate feedback through a monitor or meter reduced energy use between 5 and 15% (and between 0 and 10% through bills). Fischer (2008) updated the review of Abrahamse et al. (2005) and Darby (2006) and added 24 more studies carried out between 1987 and 2006. However, most of these studies were usually part of pilot experiences and generally used a reduced sample size that generated doubts on the robustness of their results.

As already pointed out, recent advances of research in this area owe a lot to the diffusion of developed experimental methodologies based on random and larger samples that increase the credibility of the results. Additionally, the growth of internet services has also expanded the analysis to other channels and goods. For example, Gleerup et al. (2010) carried out a random field experiment in Denmark with 1.452 households, part of whom were informed by email or cell phone texts that they had used an exceptionally high amount of electricity in a certain period. Informed consumers reduced their energy use by 3% on average, although this value was not significant for all the model specifications, which could be due to the small size of the treatment groups. Also, in other field trial carried out in Linz (Austria) with more than 1.500 households Schleich et al. (2013) sent feedback through a web portal or post with detailed information on electricity consumption and found a 4.5% average decline of annual electricity consumption in the treatment group. However, with a quantile regression model they found that this effect was not statistically significant for households above and below the 30th and 70th quantiles of electricity consumption.

Since the most frequent channels used to convey this feedback have been smart meters and energy bills, we next now look at them in detail.

3.2.1. Smart meters

As aforementioned, the effectiveness of feedback increases as the frequency in which it is received increases (Ehrhardt-Martinez et al., 2010) and so smart meters may increase the savings achieved.[13] These meters also allow for more rigorous experiments, as compared to the small-size, not-always-random studies carried out in the first years. Of course, the information compiled by smart meters must be conveyed to the customer, which can be done with an in-house display or through other channels such as web-based services or bills.

There are already some estimates about the effect of smart meters on energy savings. Faruqui et al. (2010) concluded that the average reduction in energy use was 7%, without accounting for the impact of time-dependent tariffs. Similarly, Gans et al. (2013) found that energy use in Ireland dropped between 11% and 17% when smart meters replaced old meters in a natural experiment. Houde et al. (2013) collaborated with Google in an experiment in which over 1.500 employees participated voluntarily. Households were randomly assigned to the treatment group, which received a device that metered energy use every 10 min and made this and other information public on a webpage. The experiment led to a 5.7% reduction of energy use, although reductions ceased to be significant after four weeks.

3.2.2. Energy bills with comparative information

Another way of giving feedback is through bills that provide information on household energy use and how it compares to others. This option has been considered since the 1980s (Ehrhardt-Martinez et al., 2010), but only recently has been proposed as an effective feedback to promote energy efficient behavior (Croson and Treich, 2014). This type of information uses social pressure to attempt to “nudge” consumers into adopting more energy-efficient decisions (DellaVigna, 2009). The most studied case consists in including information about the energy use of similar homes on the energy bill, so that consumers with a higher consumption may be inclined to reduce their consumption.[14] Thus, this informational instrument attempts to reduce incomplete information but also other behavioral failures such as limited attention (see Section 2.2). In the EU, for instance, this information is regulated by the Directive 2012/27/EU and must be included in the bill whenever possible. As compared to smart meters, bills offer a much more inexpensive way to provide feedback to achieve energy savings.

A growing number of empirical studies have looked at this matter, and are summarized in Table 3 with their technical characteristics and results. The first review, carried out by Fischer (2008) for 12 empirical studies that used some type of comparative information, did not find impacts on energy use. Fischer argued that this might be explained by the increase in consumption of lower-than-average households that cancels out the reduction. According to Schultz et al. (2007) this may be due to the lack of historical information on their own consumption (injunctive messages) which creates a potential rebound effect on their own consumption (boomerang effect) as they found for California.

Nola et al. (2008) ran a first experiment in California in which they found that, although households do not consider this comparative information relevant for making decisions, those that received this information in a second experiment reduced their energy use. However, the results from these two studies are limited by the small size of the samples used. More recently, the U.S. utility OPower carried out a large-scale random experiment, the Home Energy Report.[15] Its goal was to assess the effect of including comparative information about the energy use of a similar home in the gas or electricity bill and, following Schultz et al. (2007), it also incorporated historical information about the own consumption of the home. Several studies have been produced from this experiment: Allcott (2011) found that, for a sample of 600.000 households distributed across the U.S., this information reduced energy use by 2% on average. Ayres et al. (2012) used two sub-samples, one for electricity-only use and the other for gas and electricity, showing a reduction in energy use of between 1.2% and 2.1%, although the effects were limited in time (7 months for gas and 12 months for electricity). The issue of persistency of effects after the end of the intervention was specifically addressed by a recent paper by Allcott and Rogers (2014) with the use of a longer sample of the OPower experiment. The results from this paper suggest that the effect decays two weeks after the intervention ends,[16] although the persistency is higher if the intervention is

[13] Smart meters are being rolled out differently in different regions, with some technical and data privacy problems. For instance, the 2012/27/UE Directive requires all member states to ensure that all customers have real-time meters. However, the cost effectiveness of meters for energy savings is not clear, as shown by Conchado and Linares (2012), who review the economic impacts of these programs.

[14] Schultz et al. (2007) warn that, in order to avoid a negative effect in households with lower-than-average consumption, it is also recommendable to include information on the historic consumption of the household.

[15] Accessible at http://opower.com/.

[16] In a field experiment carried out in Japan in 2012 and 2013, Ito et al. (2015) also found that the effect of suasion information sent to households to voluntarily implement energy conservation measures during peak demand quickly diminished after repeated interventions. However, their results were based on a non-random sample.

Table 3
Empirical evidence from studies of comparative energy bills.

Study	Sample	Results
Nola et al. (2008)	810 households, California	Consumption decreases
Schultz et al. (2007)	290 households, California	−1.22 kW h/day for households above the average using descriptive information −1.72 kW h/day for households above the average using descriptive and injunctive information
Allcott (2011)	600.000 households, U.S.	−2% average, significant heterogeneity
Ayres et al. (2012)	84.000 households, U.S.	−1.2% gas −2.1% electricity
Costa and Kahn (2013)	Treatment group of approximately 35.000 households. A control group of roughly 49.000 households that have never received a Home Electricity Report in the U.S.	−3.1% consumption for: registered liberal who pays for electricity from renewable sources, who donates to environmental groups, and who lives in a liberal neighborhood reduces consumption +0.7% for: registered as conservative do not pay for electricity from renewable sources, do not donate to environmental groups, and live in the bottom quartile liberal neighborhood
Allcott and Rogers (2014)	The initial experiment population was 234.000 households in the U.S.	Consumption decreases immediately but decays after less than two weeks.

Source: The authors.

longer. This could be explained by a gradual change in both the habits and the technology of consumers.

Even though these studies use very large databases that ensure robust results, it is worth noting that there is a large heterogeneity in the residential sector difficult to capture in the models (Costa and Kahn, 2013). Therefore, savings may vary substantially depending on the typology of the households and their political or environmental orientation. Moreover, the counterfactuals used for each study are different and thus it is not possible to make direct comparisons among the results.

3.3. Energy audits

Energy audits are another way to convey information about energy efficiency to consumers. With personalized audits, consumers may be aware of the potential for reducing energy use in their homes. Therefore, their major advantage is that they offer tailored information. This policy instrument attempts to reduce several types of informational failures: incomplete and asymmetric information, transaction costs, uncertainty, and some behavioral failures. However, the cost is high, and it often requires support from public administrations or energy companies. In the EU Directive 2012/27/EU requires member states to promote and facilitate energy audits among final consumers, as long as they are cost-efficient, carried out by certified agents, and supervised by national authorities.

In a recent field experiment Alberini and Towe (2015) estimate the energy savings generated by two energy efficiency programs, one of which consists of a free of charge energy audit carried out in Maryland. They used a “triple difference” approach together with different matching techniques that allow them to find similar control households, and found a treatment effect of a 5% decline in energy usage. Yet researchers agree that the major difficulty in assessing this informational instrument is the self-selection bias due to the voluntary nature of audits. The above-mentioned review of Abrahamse et al. (2005) compiles the results of five studies of energy audits, carried out before 2004. Results are heterogeneous: while some papers find a significant reduction in electricity and gas use, others do not find any evidence of this reduction. Once again, the disparity of results may be explained by the heterogeneity of the samples. Frondel and Vance (2012) reach a similar conclusion, finding very diverse outcomes for energy audits in Germany that depend on the households studied. They even encounter cases in which the information provided through the audit renders negative effects for energy efficiency investments. These problems led Palmer et al. (2011), in a survey of almost 500 energy service companies, to inquire on the difficulties encountered by this instrument. The major problems they pointed out were difficulties in understanding the results of the audits, their direct cost, and the cost of the recommended improvements.

4. Policy implications

In sum, although informational instruments seem to be very promising, they also present clear shortcomings. Despite clearly adding very relevant channels to those already covered by conventional instruments, some factors explaining the Energy Efficiency Paradox in the residential sector still need to be addressed and researched. One is the large transaction cost for households when considering investments in energy efficiency, and which is partly addressed by certificates, feedbacks and audits, by reducing the cost of information. But even when investments are completely funded by the government, there may be significant transaction costs that could discourage consumers from investing even if they have been provided with the information to reduce energy consumption (Fowlie et al., 2015). Reducing transaction costs for households is a difficult issue, similar to the one presented by bounded rationality (or limited attention) inherent to many of these decisions. Innovative approaches are clearly required here. Another very relevant problem requiring novel institutional arrangements is the principal-agent problem, pervasive in this sector, which is neither directly addressed by conventional nor informational instruments. Although it can be reduced by some information instruments, such as energy certificates, or by imposing minimum energy efficiency standards for rental properties, the misalignment of incentives cannot be corrected completely by these policies. In addition, the use of standards is only reasonable for new rental buildings, but not for existing ones.

One way to move forward may be to combine instruments and promote new designs for conventional instruments. The Carbon Reduction Commitment (CRC) of the UK, a complement to the EU Emissions Trading System for the commercial sector that addresses low-energy-intensive activities in high demand is a good example. Another interesting instrument is the one recently proposed by Rodríguez et al. (2012) and Gago et al. (2013): a new tax on energy inefficiency. This tax would be based on the energy certificate system, and would employ a fixed charge per area unit, depending on the type of certificate. Another option, mentioned above, would be the combination of minimum energy efficiency standards with price signals, as in the two-part instrument proposed for vehicles by Eskeland and Devarajan (1996).

Of course, more research is needed to study the applicability and effectiveness of these new designs. New information and communication technologies also open up new possibilities to design instruments, even though this may also involve high costs. This takes us to our final point, which is the need to study all these instruments not only from the point of view of effectiveness but also from the perspective of welfare. Little research is available on this, but some authors already indicate possible situations in which the welfare effect is not clear. Mahenc (2007), for example, studies the possible overpricing of green products, whereas Houde (2014b) and Cohen et al. (2014) argue that manufacturers of household appliances may respond to energy certificates and standards with price discrimination and other strategies that result in welfare losses for consumers. Nauleau et al. 2015, also examine what is the most appropriated type of energy efficiency subsidies in markets with negative externalities and price–quality discrimination, as it is the case of the appliances or energy retrofitting industry. However, no studies have been carried in the residential building market as of yet. The cost–benefit analysis for the deployment of smart meters, for instance, is not clear either: given the still pre-commercial status of many of the technologies associated, the cost of deploying the smart meters and the communication infrastructure required outweighs the benefits they can provide in terms of energy savings (see e.g. Conchado & Linares, 2012).

5. Conclusions and future research

Conventional energy efficiency policies such as building codes or standards, or pricing systems, have not been effective in the residential sector, which is actually increasing its energy use (and carbon emissions) in most countries. Part of the reason for this may lie in the complexity of this sector, with its many dualities (renters vs. owners; commercial vs. residential, etc.) that complicate institutional arrangements and the use of traditional instruments. However, another very powerful explanation is that the assumption of perfect information and rational decision-making is less valid in this sector than it is in others. Indeed, many researchers have identified the significant contribution of information and behavioral problems to the Energy Efficiency Paradox in this sector.

Therefore, it is necessary to consider other tools that directly address these problems, and to do that not only on effectiveness but also on efficiency terms. Implementing some of these alternative instruments may be substantially less costly than implementing the traditional ones and thus could bring about a simultaneous improvement in the efficiency of public policies. A relevant question then is how effective are these information-based instruments. In this paper we have reviewed the evidence on the effectiveness of energy certificates and labels, feedback programs, and energy audits. Our results reveal that there are clear advantages for some yet not for others as we summarize next.

Energy certificates and labels show great potential. Most of the available studies indicate a positive WTP by consumers for them (up to 20% in some cases), which is consistent with the reductions observed in energy use. This result has not only been obtained for buildings but also for appliances and vehicles. Yet some of this information must be taken with care as, first, results are less positive for residential buildings than they are for commercial buildings. This signals lower value of the information in the former, which in turn may be related to a less-rational decision-making process. Clearly, there is a need to address more factors in play in the residential sector.

Second, there are cases in which WTP is non-significant or even negative. This may be owed to different reasons such as the way certificates are designed. The studies reviewed show that the way the information is framed determines the results: it is more powerful to show energy savings or economic losses than it is to present potential benefits. Government backing is also much valued, giving credibility and stability to the certificates. These features probably explain why informal or private information procedures show a limited effect, a much lower one than certificates do. Finally, consumers may be deterred by higher maintenance costs, or potential rebound effects of more efficient equipment even if the certificates show energy savings.

In turn, feedback programs are shown to achieve moderate energy savings, of around 2–3%. These programs can be very inexpensive, though, as is the case when the feedback is given through energy bills, and they can also use social pressure (through comparative information) as a driver for energy efficiency. Therefore, in these low-cost implementations they can be preferable to other policy alternatives.

However, research has shown that the frequency with which the feedback is given matters a great deal, and energy bills are not that frequent. Here smart meters may play a much bigger part, in fact frequent feedback information provided by these devices has shown to achieve reductions of up to 15% in energy use. Unfortunately they are more expensive, as mentioned earlier, not only because of the cost of the smart meters but also due to the very high cost of the communication infrastructure required. Two more important problems must also be noted. The first is the fact that feedback might result in increases in energy use in the case of consumers that are already efficient. Some authors suggest including historic information to control for this. The second and most relevant problem is the persistency of the savings, usually quite low, which indicates that habit-formation and technological changes seem to require longer and more frequent interventions.

Finally, many governments have promoted a very popular instrument: energy audits. These audits are personalized, therefore able to address heterogeneity, and have many political economy advantages because they are typically associated to subsidies (easier to accept than additional charges for a certificate, for example), and because they generate a significant level of activity for the ESCO (energy-service company) sector, which will therefore back them strongly compared to other instruments that generate less revenue. However, the results of the reviewed studies have rendered mixed, i.e. not clearly positive, effects. Combined with its high cost and its complex implementation, the preceding conforms audits as the least interesting of all the instruments reviewed in this paper.

In this article, as in many review papers, we end up with a picture of informational instruments that is not as clear as a one-handed policy maker would like. We point to the many advantages of some well-designed informational instruments, such as energy certificates or feedback programs, and the limitations of energy audits. However we also observe that much more work is required to explore the potential of alternative instruments and assess their cost-efficiency. This is undoubtedly an area full of potential for energy economic researchers.

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Appendix A

Table A1. A summary of the major behavioral failures.

Type	Behavioral failure	Explanation
Deviations from rational theory of choice	Framing	The way a problem is framed impacts the final decision.
	Preference reversal	There may be differences between values and choices which result in reversal of preferences.
	Preference intransitivity	Preferences may not be consistent, and may form on the spot, resulting in intransitive cycles.
	Independence of irrelevant alternatives	Alternatives that should be irrelevant become very important for the final

Table A.1 (*continued*)

Type	Behavioral failure	Explanation
		decision.
	Endowment or "status-quo" effect	Tendency to value more what we have, or the starting situation
	Gambling and insurance	Partly based on the latter (the starting or reference point), people will have different attitudes towards risk depending on its magnitude and starting point.
	Sunk cost fallacy	People consider sunk costs in their decisions, although they should not, based sometimes on self-discipline or stability of decisions.
	Mental accounting	People allocate different expenses to different categories, as a way to deal with complexity in budgeting.
	Dynamic inconsistency	Preferences change when decisions come closer.
	Bounded rationality or limited attention	People are not able to use all the available information due to time or effort constraints.
	The paradox of choice	More options result in less utility (maybe because of larger regret).
	Emotions	Emotions, altruism, social norms, may have a significant effect on decisions.
Biases when dealing with uncertainty	Representativeness/Conjunction fallacy	People look for internally-consistent stories, even if they go against probabilities. It is also used when people extrapolate small samples to large ones.
	Availability	People make judgments about the probability of events by how easy it is to think of examples.
	Anchoring	Estimations are biased by the number initially provided.
	Gambler's fallacy	Based on misconceptions of randomness, people are not able to estimate the likelihood of random sequences.
	Selection bias	When the sample selected is not random, results will be biased.
	Aversion to uncertainty	People assign lower utility to results for which probabilities are not known.

Source: The authors.

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