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Energy efficiency as a credence good: A review of informational barriers to building energy savings

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Abstract

Information problems have early been suspected to be the main barrier to energy-efficiency investment. I review the vast yet piecemeal research that has been carried out since. Focusing on energy efficiency in buildings, I organize the review around the concept of credence good: just like that of auto repairs or taxi rides, the quality of energy-efficiency measures is never fully revealed to the buyer; as a result, it is subject to multiple information asymmetries. My first contribution is to distinguish symmetric-information problems from information asymmetries. The former arise when information is either incomplete or imperfect, but equally shared by contracting parties; as non-market failures, these can be addressed by technological progress and insurance markets. My second contribution is to give structure to the information asymmetries associated with energy efficiency by disentangling screening, signalling, moral hazard and price discrimination within a variety of contractual relationships involving buyers and sellers, owners and renters, and borrowers and lenders. I find evidence of information asymmetries to be compelling in landlord-tenant relationships, unclear in real estate markets, and scarce in retrofit contracting and financing. I conclude by discussing the intricacies between informational and behavioural problems in energy-efficiency decisions.

Keywords

Energy-efficiency gap, imperfect information, adverse selection, principal-agent problems, home energy retrofit

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1 Introduction

Energy-efficiency investments in residential and commercial buildings have uncertain returns. Long payback periods make them sensitive to an array of contingencies. Their net present value depends on stochastic factors such as future energy prices and weather conditions. It moreover depends on heterogeneous factors such as decision-makers' preferences (e.g., tolerance to cold, lighting habits) and constraint sets (e.g., physical properties of buildings, energy distribution infrastructure). To complicate matters further, many energy efficiency technologies require expert services, notably installation tasks, the quality of which can be difficult to verify. Lastly, energy efficiency measures involve a number of stakeholders, all of whom having vested but not necessarily aligned interests. This frequently includes, in addition to buyers and sellers, users of energy-consuming assets and, as purchase prices can be substantial, credit suppliers. In this context, who's to blame if an insulation investment doesn't deliver as promised? The tenant behaving in unexpected ways, a non-diligent installer, flawed engineering simulations, or simply bad luck with weather forecasts?

Such a bewildering array of possible answers illustrates the credence-good nature of energy efficiency (Sorrell, 2004). By definition, the value of credence goods is never fully revealed to the buyer, even long after purchase. Classical examples include medical treatments, taxi rides or auto repairs. As illustrated above, energy efficiency shares with these counterparts the following characteristics: sellers face heterogeneous buyers; the quality of the product is not easily verifiable; nor is it subject to complete liability rules. Altogether, these characteristics create a variety of information asymmetries, including adverse selection, moral hazard and price discrimination (Dulleck and Kerschbamer, 2006).

Albeit pervasive in the economy, information asymmetries have specific implications in the context of energy efficiency. As we shall see in this essay, they can explain low uptake of energy efficiency, a long-standing paradox known as the energy efficiency gap (Jaffe and Stavins, 1994). The problem has initially been identified through abnormally high implicit discount rates in decisions to purchase energy-efficient assets, suggesting that consumers discard supposedly profitable investment opportunities (Hausman, 1979; Train, 1985). More recent studies document another manifestation of the energy-efficiency gap, namely that energy savings measured after investment underperform those predicted by engineering simulations before investment (Metcalf and Hassett, 1999; Fowlie et al., 2015). Three categories of economic problems are usually put forward to explain the energy-efficiency gap: market failures that truly impair socially desirable energy-efficiency investments; non-market failures that restrict investment without affecting social welfare; and behavioural anomalies leading to individually irrational investment, with unclear implications for social welfare (Gillingham et al., 2009; Allcott and Greenstone, 2012; Gerarden et al., 2017).

Informational problems have been early pointed out as the main cause of the energy-efficiency gap (Howarth and Andersson, 1993; Huntington et al., 1994). As research has grown substantially since, the contention can now be examined. I hereby take stock and review the vast yet piecemeal research into information in energy-efficiency decisions. A preliminary finding is that information problems are ill-characterized within the usual three-fold categorization. I sort this out by stressing the dichotomy between market and non-market failures, which I restate as one between, respectively, asymmetric and symmetric information. I thereby complement existing research that has focused on behavioural anomalies as the main category of problems at the source of the energy-efficiency gap

(Gillingham and Palmer, 2014; Allcott, 2016). My review is closest to Ramos et al. (2015), who also review information problems, with the important difference that I place less emphasis on behavioural problems and more emphasis on information asymmetries.

My contribution is two-fold. First, I find symmetric-information problems to be important. This includes incomplete information – e.g., infrequent billing of energy use, incomplete disclosure of product attributes, need for pre-retrofit audits – and imperfect information – e.g., uncertainty about energy prices and weather conditions. These problems are frequently mistaken for information asymmetries or behavioural anomalies, which is a source of overestimation of the energy-efficiency gap. While technological progress and insurance markets should suffice to overcome them, the effectiveness of these private solutions has not been examined.

Second, I find information asymmetries to be of a broader variety than previously thought. Assessment of their magnitude is however subject to methodological caveats. I disentangle screening, signalling, moral hazard and price discrimination within a variety of contractual relationships involving buyers and sellers, owners and renters, and borrowers and lenders. Information asymmetries appear to be important in building rental (signalling), in particular when rents include utility expenditures (moral hazard, screening). Evidence is more mixed in building sales. Buyers are found to respond to energy efficiency, yet only a handful analyses separate out the effect of energy-efficiency labels from that of other observable energy-efficiency characteristics. Lastly, important information asymmetries have been overlooked in the installation (moral hazard, signalling) and financing (screening, moral hazard, price discrimination) of energy-efficiency measures. This remains an important research gap, as these transactions are key to scaling up energy efficiency.

The review focuses primarily, though not exclusively, on evidence gathered from revealed-preference studies conducted in the residential sector. It does not address in detail behavioural anomalies, a problem highly relevant to energy-efficiency decisions yet fairly well covered elsewhere. Their relationships with information asymmetries, which are conceptually and empirically important, are nevertheless discussed briefly at the end of the paper. Another discussion follows on what can be expected from rapidly developing information technologies in overcoming barriers to energy efficiency.

The review proceeds as follows. Section 2 reviews symmetric-information problems. Section 3 introduces various types of information asymmetries with the example of home energy retrofits. Section 4 details adverse-selection problems. Section 5 details principal-agent problems. Section 6 puts the findings in perspective and Section 7 concludes.

2 Symmetric-information problems

I define symmetric-information problems as information imperfections or gaps identically faced by contracting parties. These are not market failures in that no party extracts an informational rent from the other. Market outcomes can be improved by information technologies, the development of which does not *a priori* require public support.[1] Though symmetric-information problems are normal

[1] Public support can be warranted if information technologies are subject to classical innovation market failures. The question of whether this is the case in the context of energy efficiency is outside of the scope of this paper.

components of well-functioning markets, the trouble in energy-efficiency research is that they are often ignored when predicting economically efficient levels of energy efficiency. This consistently leads to overestimation of the energy-efficiency gap.

2.1 Incomplete information

Incomplete information here denotes situations in which part of the information needed to make a decision is missing, or costly to obtain with current technology. The problem can be identified by observing changes in adoption patterns when people are provided with more complete information about energy efficiency. As detailed below, incomplete information affects several decision variables.

2.1.1 Energy operating costs: Evidence from infrequent billing

The cost of operating energy-consuming devices is usually not known in real-time.[2] In the absence of consumption displays, which remain far from widespread, information is incomplete in at least two respects: it is only provided occasionally when fuel tanks are filled or infrequently when electricity and natural-gas meters are monitored; it concerns a bundle of usages. How does more complete information affect market outcomes?

A number of studies have examined experiments increasing the frequency of information through smart metering or in-home displays. These so-called feedback interventions, extensively reviewed in Abrahamse et al. (2005), Fischer (2008), Delmas et al. (2013), and Buchanan et al. (2015), are generally implemented by electricity utilities. They initially produced mixed results. Abrahamse et al. (2005) find little impact based on 38 studies. Scepticism is shared by Buchanan et al. (2013) who even document cases where more frequent information increased energy use. Delmas et al. (2013) draw slightly more positive conclusions, estimating an average reduction in energy use of 7.4% from 156 studies.

More recent studies tend to confirm the negative yet modest effect of information frequency on energy use. Matsukawa (2004) finds a significant effect of electricity monitoring devices in a Japanese experiment. Houde et al. (2013) ran an experiment with 1,500 employees from Google and found that participation in the feedback program yielded an average reduction in electricity use of 5.7%, persisting up to four weeks. In a similar experiment involving 1,500 Austrian households, Schleich et al. (2013) find an average 4.5% reduction of electricity use attributable to getting feedback, however concentrated around the median of the distribution. Delmas and Lessem (2014), in an experiment on UCLA campus find that real-time feedback was ineffective, while publicly visible conservation ratings reduced electricity use by 20%, with more effect for above median energy users. Jessoe and Rapson (2014) find that informed households are three standard deviations more responsive to price variations than uninformed households and that this cannot be attributed to price salience. Sexton (2015) studies the somewhat reverse experiment. The author finds that enrolment in automatic bill payment (which decreases the frequency with which consumers receive information) increases electricity use by 6% to 7%. Chen et al. (2015) find evidence that consumers inaccurately estimate energy use from appliances. Lastly, Tiefenbeck et al. (2016) finds a large effect of 22% on showering.

[2] I focus here on information about energy quantities, which is more often missing than information about energy prices. Still, it is important to note that peak versus off-peak electricity prices and energy tariff menus are not always displayed transparently (e.g., Sexton et al., 1989).

Overall, the effect of more frequent information on energy use seems to be specific to individual preferences, to the point that it its sign is ambiguous. It also seems to be more effective when targeting specific energy services. Lastly, it seems to vanish when information frequency is reverted to normal. One difficulty for evaluation is that most experiments include other treatments such as tips or comparison with peers, which might confound identification of the purely informative effect. We will return to that point in Section 6.

2.1.2 Performance of standardized products: Evidence from energy labels

Next to information available while operating energy-consuming durables, information available at the time of purchase might also be incomplete. For standardized products such as electrical appliances, information about product performance is generally produced by normalized engineering calculations and displayed through labels. Assuming that labels are trustworthy,[3] how do consumers respond to the more complete information they convey? As we shall see, here too it is difficult to disentangle information and behavioural effects.

A few studies have examined the impact of the EnergyGuide label, a mandatory label implemented in 1979 in the United States reporting a cost figure based on average national usage and energy prices. Houde (2014) examines refrigerator purchases and finds that a fraction of consumers respond to this piece of information in a privately rational way. Meanwhile, others over-respond, an effect the author attributes to the coexisting Energy Star label, a voluntary label providing coarser information. A third fraction of consumers do not respond to either label. Newell and Siikamäki (2014) also find that Energy Star leads to cost-effective decisions, while over-reaction cannot be excluded. Davis and Metcalf (2016) find a heterogeneous response to EnergyGuide in an online stated-choice experiment, with more relevant information about local energy price leading to more rational decisions.

Mandatory labels in place in the European Union and China are framed within a discrete performance scale, thereby reconciling the accuracy of EnergyGuide and the conciseness of Energy Star. Zhou and Bukenya (2016) show in a discrete choice experiment that consumer's mean willingness-to-pay for efficient air-conditioning systems increased when the performance was framed in a more segmented way. The effect is more pronounced at the high-utilization end of the distribution. In the European Union, a similar experiment was conducted by Andor et al. (2016), who find results similar to Houde (2014), namely that some people respond to information only, while others respond to norms. In contrast, in an eye-tracking experiment, Waechter et al. (2015) find little impact of labels in decision-making.

In case labels are not sufficient, sales agents can offer an additional information channel. A few studies have examined this contention in field experiments. Anderson and Claxton (1982) found a positive impact of sales staff support on label awareness, but no apparent impact on refrigerator choice in 18 department stores in Western Canada. Likewise, Kallbekken et al. (2013) find no statistical effect of training of sales staff on the purchase of tumble driers and fridge-freezer in six megastores in Norway. In a randomized controlled trial involving 20,000 agents in call centres of a large US retailer, Allcott and Sweeney (2016) find that, unless combined with large rebates, information and sales incentives alone have zero statistical effect on the sales of water heaters.

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[3] At least two caveats apply here. First, the tests preceding label attribution could be subject to falsification, just like the widely publicized Volkswagen case revealed in the automobile sector (U.S. EPA, 2015). To my knowledge, the issue has not been investigated in appliances and other energy-consuming assets. Second, sellers can exploit labels to price-discriminate. We return to that point in Section 5.2.

2.1.3 Performance of tailored measures: Evidence from energy audits

In large-scale projects such as home energy retrofits, which combine several measures and products within an idiosyncratic architectural layout, ex ante assessment of energy savings cannot be standardized. Investment appraisal requires customized audits which typically come at a cost of a few hundred dollars (Alberini and Towe, 2015; Palmer et al., 2015).

Do audits produce accurate predictions? Evidence so far suggests a negative answer. The problem was first identified by Metcalf and Hassett (1999), who found that returns to insulation underperformed audit predictions. The result has recently been confirmed by other studies, such as Fowlie et al. (2015), Graff Zivin and Novan (2016) and Giraudet et al. (2018). Graff Zivin and Novan (2016) find that 79% of predicted savings are actually realized. Giraudet et al. (2018) find similar figures, on average, with ratios ranging from 31% to 352% depending on the measures considered. The discrepancies come from measurement errors and complexities inherent in thermal simulation algorithms (de Wilde, 2014; Hsu, 2014).[4] They can also be due to market failures such as moral hazard, as we will see in Section 5.

The next question of interest is: how (possibly inaccurate) audits modify investment decisions? This can be directly assessed by observing purchase behaviour. Early assessment of McDougall and Claxton (1983) found little or no effect of audits on homeowner's conservation activities. Frondel and Vance (2013), applying a mixed logit model in Germany find a mean positive effect, though with substantial heterogeneity, some people exhibiting negative responses to audits. Murphy (2014) finds even more counter-intuitive results in the Netherlands, with a treated group not reacting to audits while non-treated individuals make more energy-efficient investments. Palmer et al. (2013, 2015) find in a survey that the depth of an audit, as measured by the inclusion of such items as energy bill assessment, blower door test or infrared imaging, is an important determinant of follow-up on audit recommendations. Considine and Sapci (2016) estimate a significant but modest effect of audits on investment in a discrete-choice analysis of a program conducted in Wyoming. In the commercial sector, Anderson and Newell (2004), find that half of audits are followed up. Comparable effects have been observed in Germany (Schleich, 2004) and Sweden (Backlund and Thollander, 2015). In Italy, Barbetta et al., 2015 find no effect of audits on either the number of investments or the amounts invested in local public administrations.

The effect of audits can also be assessed indirectly by examining variation in energy use, under the assumption that it follows from unobserved investment. Using this technique, Hirst and Goeltz (1985) found that receiving a free audit induced significant but small energy savings. More recently, Alberini and Towe (2015) find that participating in an audit program yields 5% energy savings on average, an effect commensurate with that estimated for rebates in the program.

Altogether, it is difficult to disentangle the quality of audits and their effect on investment. In addition, selection bias is an important concern in the small-scale studies reviewed here.

[4] One source of error is the so-called "prebound effect" which arises when the baseline energy use against which savings are predicted is overestimated (Sunikka-Blank and Galvin, 2012).

Results indicate that information relevant to energy-efficiency decisions is incomplete and that providing better information improves market outcomes. Yet the overall effect tends to be small and heterogeneous. The information gap is therefore probably modest.

2.2 Imperfect information

In addition to being incomplete, information about energy cost can be imperfect, in the sense that it bears some randomness. Energy prices are volatile in the short to medium term; energy needs, in turn, are determined by intrinsically random factors such as the weather. Combined with the irreversible nature of energy efficiency improvements, such randomness creates option values (Dixit and Pyndyck, 1994). These affect investment outcomes if decision-makers are risk-averse, which seems to be a valid assumption in the context of energy efficiency (Farsi, 2010). Using calibrated simulations, Hassett and Metcalf (1993) pointed out early that option values alone could entirely explain the high hurdle rates observed in energy-efficiency decisions. Sanstad et al. (1995) objected that this was only valid for a narrow range of decisions in which delay is not costly – unlike, say, window replacement, which is more expensive alone than if included in an earlier retrofit. Baker (2012) further restricts Hassett and Metcalf's result to binary decisions – for instance, whether or not to insulate – as opposed to discrete choices. In contrast, Ansar and Sparks (2009) follow Hassett and Metcalf's line and argue that incorporating technological change can produce high option values.

Whatever their size, option values, if unaccounted for, can be a source of overestimation of the energy efficiency gap. While insurance markets could provide a private solution to the problem, case studies are virtually inexistent.

3 Asymmetric information: A framework

Energy efficiency is subject to verifiability, liability and heterogeneity issues which together make the essence of credence goods and create information asymmetries – true market failures requiring public intervention (Dulleck and Kerschbamer, 2006). The problems are magnified by the high upfront costs and multiplicity of stakeholders involved in energy-efficiency investments. To illustrate, let us consider the measure which epitomizes these characteristics: home energy retrofit, e.g., insulation and improvements on weatherization systems. As summarized in Figure 1, the homeowner, who is central to the investment decision, may contract with four economic agents (some of whom might be herself): a tenant whose utility bill may or may not be included in the rent; a contractor selling and installing durable goods; a credit supplier; a subsequent buyer of the retrofitted home.[5]

[5] For lack of empirical evidence, I do not include other actors who too can engage in principal-agent relationships, such as energy suppliers, building certifiers and sales agents.

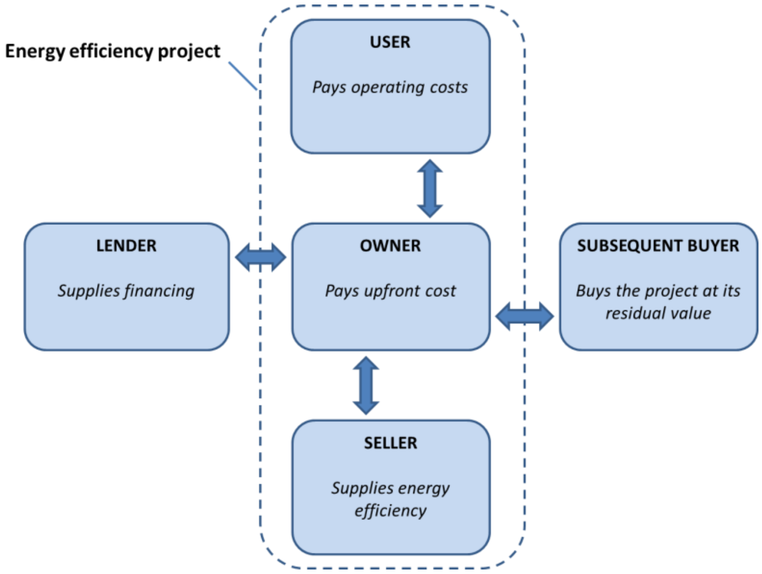

Figure 1: Main stakeholders and contractual relationships in home energy retrofits

Each of these relationships can be subject to a variety of information asymmetries, which I review below. I use the standard terminology of Mas-Colell et al. (1995), who classify information asymmetries in two broad categories – adverse selection and principal-agent problems – each encompassing subcategories – screening and signalling on the one hand, moral hazard and price discrimination on the other. The findings are summarized in Table 1.

4 Adverse selection

Adverse selection occurs when part of the relevant information is hidden to one party. Specifically, screening issues occur when the seller cannot observe buyers' types and signalling issues occur when the seller is unable to convey the quality of its products to prospective buyers. Either problem results in too little quality in the market – so-called lemons.

4.1 Signalling issues

4.1.1 Building sales

Perhaps the longest-studied information asymmetry associated with energy efficiency is signalling in building sales. The intuition is that hard-to-observe energy efficiency of a building unit is unlikely to be capitalized into sale prices. Research into the topic started in the early 1980s. At the time, energy efficiency was measured by past billing data or coarse labels describing the thermal integrity of the unit. Hedonic analyses found evidence of capitalization of energy efficiency into home sale prices (Johnson and Kaserman, 1983; Dinan and Miranowski, 1989; Gilmer, 1989; Nevin and Watson, 1998). This early literature was however criticized for failing to appropriately take into account the fragmented and local nature of housing markets and the difficulties associated with measuring costs and benefits of energy efficiency in housing (Laquatra et al., 2002).

The topic attracted renewed interest in the early 2010s with the advent of energy performance certificates such as that promoted by the European directive (hereafter EU-EPC) and the LEED and Energy Star labels in the United States. Larger datasets and more modern hedonic methods permitted more credible identification. Studying commercial buildings shortly after energy-efficiency labels became mandatory, Fuerst and MacAllister found that labelled buildings carried a price premium in the United States (Fuerst and MacAllister, 2011a) but not in the European Union (Fuerst and MacAllister, 2011b). Brounen and Kok (2011) identified a price premium associated with the EU-EPC in the Netherlands. Murphy (2014) nuances the finding by surveying purchasers, arguing that the EPC had little influence in sales negotiation. Kahn and Kok (2014) find a premium associated with LEED, Energy Star and other "green" labels in housing California. Hyland et al. (2013) and Stanley et al. (2016) find a similar premium in Ireland and Dublin, respectively. Harjunen and Liski (2014) find that more efficient heating technologies such as electric and district heating are capitalized in the Finnish housing market. Fuerst et al. (2015) find a significant effect of the EU-EPC in England. Myers (2016) finds evidence that changes in relative fuel prices cause changes in relative housing prices in Massachussets in a way that is consistent with full capitalization of energy savings. Lastly, Wahlström (2016) finds evidence of capitalization of the EU-EPC in Sweden. Like the responses discussed in Section 2.1.2, capitalization sometimes exceed the present value of energy savings. This is the case in US office buildings (Eichholtz et al., 2010, 2013) and homes from three US cities (Walls et al., 2017).

These studies together provide compelling evidence of full capitalization of energy-efficiency labels. They are less conclusive, however, as to whether labels fill an information gap. After all, the early studies reviewed above, despite their shortcomings, suggested that capitalization of energy efficiency was already effective prior to label implementation. Modern evaluations of labelling policies, in turn, do not compare situations with and without labels, which is the only way to determine whether labels operate by levelling the information shared by the buyer and the seller – thereby eliminating an information asymmetry – or simply by repeating information decision-makers can gather from observable features.

The most recent studies on the topic are beginning to fill this gap. Exploiting a dataset in which some dwellings were sold multiple times in Oslo, Norway, Olaussen et al. (2017) find that current EPCs explain sale prices in a way consistent with the studies discussed above, but also explain the prices of transactions that occurred before implementation of the EU-EPC policy. Furthermore, the authors find no evidence of a price premium after controlling for dwelling fixed effects. These results suggest that labels provide no additional information. Similar conclusions are reached by Fesselmeyer (2018) by exploiting price variation before and after certification in Singapore.[6] In ongoing work, Frondel et al. (2016) exploit a shift from voluntary to mandatory disclosure of the EU-EPC in Germany and find that it causes a contraction of the energy efficiency premium for owners who would not voluntarily disclose. This can be interpreted as evidence that sellers of low-efficiency dwellings did not voluntarily engage in signalling.

4.1.2 Building rental

The question of capitalization similarly applies in rental markets: Do more energy-efficient buildings rent with a premium? Existing studies tend to offer positive answers, for instance Fuerst and McAllister (2011a) and Eichholtz et al. (2010, 2013) in US office buildings, Kok and Jennen (2012) in commercial buildings in the Netherlands, Heyland et al. (2013) in the Irish residential sector. Reichardt (2014) finds rent premia that exceed the value of savings on operating expenses in the United States. Like in building sales, these studies are limited in their ability to disentangle the purely informative effect of labels from other potential effects. Indeed, Bala et al. (2014) find that rents in

[6] Similar results are obtained in the Korean market for televisions (Park, 2017).

Brussels in 2001 increased with observable features such double glazing and wall insulation, which suggests that energy efficiency was already capitalized without labels. In ongoing work, Dressler and Cornago (2017) address this methodological gap by exploiting a shift from voluntary to mandatory certification in Brussels similar to that exploited by Frondel et al. (2016) in housing sales. Their results provide suggestive evidence of strategic non-compliance with mandatory disclosure in those units, the EPC of which is below average.

Failure to signal energy efficiency in rental buildings can also be identified by comparing the efficiency of rented and owner-occupied units, all other things equal. Research along this line suggests that rented dwellings are less efficient than owner-occupied ones. Brechling and Smith (1994) find lower ownership of energy-efficient assets in rented properties than in owner-occupied ones in the United Kingdom. Scott (1997) finds similar results in Ireland. Davis (2012), using the U.S. Residential Energy Consumption Survey (RECS), documents that renters are significantly less likely to report having energy-efficient appliances such as refrigerators, clothes washers and dishwashers. Gillingham et al. (2012), using the same database, report that owner-occupied dwellings in California are 20% more likely to be insulated in the attic or ceiling than rented ones. Melvin (2018) extends the result to water heating, window thickness and weatherization. Myers (2015) finds that energy price movements cause shifts in rents of energy-efficient units when rents include utilities, but not otherwise, suggesting the market does not convey information about energy use. In Europe, Krishnamurthy and Kriström (2015) report that owners are more likely to have energy-efficient appliances, better insulation and heat thermostats than tenants.

The evidence here is clear: Signalling issues affect the rental of energy-efficient buildings. This may be due to rigid regulations that prevent landlords from passing investment costs onto rents. While labels seem to improve decisions, evidence is scarcer as to whether they encourage landlords to initiate energy-efficiency improvements.

4.2 Screening issues

4.2.1 Utility-included rent contracts

In many countries, rental contracts frequently include energy operating costs. In the United States, for instance, approximately 60 percent of housing rental contract include at least one energy or water utility (Choi and Kim, 2012). How does a landlord offering utility-included contracts adjust rents to the tenant's specific energy usage?

The question has been relatively little-studied. Levinson and Niemann (2004), using RECS and the American Housing Survey (AHS), find that rents in utility-included rental apartments are higher than for comparable metered apartments, but the difference is smaller than the difference in energy operating costs observed in the two types of apartments. This can be interpreted as a failure of the landlord to screen tenants with high-intensity energy usage. Myers (2015), similarly using the ASH and exploiting variation in energy prices finds that low-efficiency dwellings turnover faster than high-efficiency ones when tenants pay for energy, but not when utilities are included in the rent. Again, this suggests that tenants are less likely to self-select into the dwelling that best fits their preferences when they do not pay the marginal cost of energy.

These results together suggest that utility-included contracts lead to inefficient outcomes, favoring tenants with intensive energy usage and pricing others out of the market. One way to address this market failure could be to ban such contracts.

4.2.2 Energy-efficiency loans

In theory, adopting energy efficiency saves consumers money, thereby increasing their creditworthiness and reducing default risk. In a well-functioning credit market, the interest rate offered to consumers should therefore be lower for energy-efficiency investments than for otherwise similar investments. Investigating this hypothesis in commercial mortgages, An and Pivo (2018) find better loan terms for buildings that were certified green at loan origination than for other buildings which either are non-green or were certified green after loan origination. Though modest in magnitude, the effect is consistent with lenders efficiently using green labels as a screening device. Information asymmetries, if they affect energy-efficient projects, do thus not carry over to the financing process.

5 Principal-agent problems

Principal-agent problems are situations in which a principal hires an agent to perform a task. Moral hazard arises if the principal cannot observe the agent's ex post actions. Price discrimination arises if a multiproduct monopolist cannot observe the agents' types ex ante. Both categories produce undesirable behaviours and they are likely to affect the markets for energy efficiency.

5.1 Moral hazard

5.1.1 Utility-included rental contracts

Just like an insuree is expected to take little care of a product covered by an insurance contract, an energy user who does not face the marginal cost of energy is expected to over-use energy. Such moral hazard is substantiated in utility-included rental contracts. Levinson and Niemann (2004), using RECS data, find that US households use slightly more energy under such contracts. Maruejols and Young (2011) find similar effects in Canada. Gilliginham et al. (2012) similarly find in California that under such contracts, occupants are 16% more likely to change heating thermostat at night. Kahn et al. (2014) find evidence of a better environmental performance in those commercial buildings, the tenants of which face a positive marginal cost for electricity. Myers (2015) finds that landlords are more likely to make cost saving investments when they face the marginal cost of energy usage. The most credible evidence to date is provided by Elinder et al. (2017) who compare energy use before and after an intervention consisting in excluding utilities from rental contracts in Sweden. Compared to 1,000 tenants in the control group, the 800 treated tenants showed an immediate and permanent reduction in energy use by 25%.

Evidence here is compelling. All authors however underline that the effect is small in terms of excess energy use – which does not mean that welfare effects are unimportant. Here again, banning utility-included contracts could avoid over-use of energy, a problem even more critical in the presence of uninternalized energy-use externalities.[7]

5.1.2 Building retrofits

The quality of such retrofit works as attic insulation or duct sealing is hard to verify by non-experts, unless costly ex post audits involving thermo-photography or blower-door tests are commissioned. The informational context is conducive to moral hazard in the form of under-provision of installation quality by contractors.[8] Using data from a utility-sponsored retrofit program in Florida, Giraudet et al. (2018) find that energy-efficiency measures are subject to day-of-the-week effects if they are deemed hard-to-observe, but not otherwise. The day-of-the-week effect follows a specific pattern – energy savings are lower when the retrofit was completed on a Friday, as compared to other days of the week. The authors find that the problem can explain 65% of the discrepancy observed between predicted and realized savings.

Moral hazard can be addressed by professional certifications – a public solution – or energy-savings insurance – a private one. While the former incurs monitoring costs, the latter induces a moral hazard similar to that associated with utility-included contracts. Through calibrated simulations, Giraudet et al. (2016) suggest that certifications provide slightly more benefits than insurance. Note that reputation provides another private solution to moral hazard; yet to my knowledge, the issue has not been examined.

5.1.3 Energy-efficiency loans

As stated earlier, energy efficiency is supposed to reduce default risk, an important form of moral hazard in credit. Using US data from the Home Energy Rating System (HERS), Kaza et al. (2014) found that more energy efficiency, as measured by ENERGY STAR ratings, is associated with lower default and prepayment rates in residential mortgages. Applying a similar research design to commercial mortgages, An and Pivo (2018) confirm that greener buildings are associated with lower default rates. The effect is more important than that identified by the authors in relation to loan terms (cf. infra). Altogether, these results can be interpreted as efficient loan pricing, implying that information asymmetries in energy-efficiency loans are not economically important.

In home energy retrofits, an additional problem arises. Unlike other assets of comparable purchase price, say a car, an energy retrofit cannot be confiscated. Therefore, unless the retrofit is included in a mortgage, it cannot serve as credit collateral. This might lead lenders to raise interest rates in an effort to hedge against increased default risk (Palmer et al., 2012). The effect has not yet been empirically investigated.

5.2 Price discrimination

Price discrimination, also known as monopolistic screening, arises in the presence of two market failures: imperfect competition and adverse selection. A multiproduct seller having market power but no ability to screen consumer's types has an incentive to deteriorate the quality of low-end products so as to maintain high mark-ups on the sales of high-end products (Mussa and Rosen, 1978). If

[7] This prescription abstracts from benefits potentially associated with utility-included contracts, which can enable landlords to attract certain types of consumers and avoid them to install costly individual meters (Choi and Kim, 2012).

[8] In addition to moral hazard, it might be difficult ex ante to hire a diligent contractor. This screening problem is unexplored.

energy efficiency is the relevant dimension of quality, those distortions result in too little energy efficiency at the bottom of the product line (Fischer, 2005; Nauleau et al., 2015).[9] Houde (2014) exploits changes in the ENERGY STAR label in the US market for refrigerators and finds adjustments in the product line that are consistent with price discrimination. Spurlock (2013), exploiting simultaneous changes in minimum energy efficiency standards and ENERGY STAR, reaches the same conclusion for clothes washers. So do Cohen et al. (2017) using variation in energy prices in the UK market for refrigerators.

6 Discussion

6.1 Information problems and behavioural anomalies

Besides debate over the market-failure nature of barriers to energy efficiency, an important research effort has been dedicated to behavioural anomalies in energy-efficiency decisions in the past decade. Environmental topics, and energy efficiency in particular, offer interesting opportunities to test the predictions of the emerging field of behavioural economics (Shogren and Taylor, 2008; Gillingham and Palmer, 2014; Allcott, 2016). Consumers indeed seem to value energy savings in a way that is inconsistent with perfect rationality (Attari et al., 2010). Much research along this line has focused on feedback experiments with peer comparison, in which consumers are provided with information about how their energy use compares to that of their neighbours (e.g., Allcott, 2011; Allcott and Rogers, 2014). Overall, such interventions are found to strengthen conservation behaviours, however with low persistence (Ayres et al., 2012; Delmas et al., 2013). This finding suggests that social norms influence individual's behaviour, a feature not captured by the standard microeconomic model.

As transpired throughout the review, however, behavioural anomalies are difficult to separate out from information problems. Most empirical settings simultaneously involve informational barriers – incomplete, imperfect or asymmetric information – and behavioural treatments. This is especially the case with energy-efficiency labels, which can serve either as a pure information provision addressing incomplete information, as a device levelling information between contracting parties, or as a social norm provoking departures from individual rationality. In randomized experiments in the lightbulb market, Allcott and Taubinsky (2015) provide information treatments and observe how they affect consumers' willingness-to-pay for compact fluorescent lightbulbs. The authors interpret the treatment as a "pure nudge" and assume that consumers' responses reveal the average marginal inattention bias. This study is an important first step that highlights the importance of heterogeneity in consumer responses. More research is however needed to disentangle purely informative and purely behavioural effects.[10]

[9] Improving energy efficiency normally means minimizing energy use for a given level of energy service. Yet the term is frequently used in the broader sense of simply minimizing energy use, without necessarily holding energy service constant. This is typically the case in transportation, where a small car is regarded as more energy-efficient than a larger car. While a small car indeed allows one to cover more distance with the same amount of fuel, it also offers fewer services (e.g., limited capacity and comfort). If price discrimination operates along these other dimensions of energy services, it can lead to too small cars, which, if energy efficiency is used in the broader sense, can be interpreted as too much of it (Plourde and Bardis, 1999).

[10] Preliminary work by Astier (2016) is worth mentioning here. The author proposes an interesting design to separate out information provision and social norms. Online participants are first randomly assigned to complete and incomplete information environments then randomly assigned to different treatments: comparative feedback,

6.2 What to expect from information technologies?

Given the central role information technologies have come to play in the economy, it seems natural to ponder on how they can support energy-efficiency improvements, which are subject to so many information problems. The works reviewed here suggests that smart metering and in-home displays of energy use can significantly improve market outcomes. So can emerging technologies such as thermo-photography and other tests which enable verification of building performance. Nevertheless, the algorithms used to predict energy savings still seem to lack accuracy. Another area for improvement is the development of platforms facilitating search for retrofit contractors.

The question examined here echoes a broader reflection about whether recent breakthroughs in information technology mean the end of information asymmetries (Cowen and Tabarrok, 2015). Preliminary research warrants healthy scepticism. For instance, internet markets do not seem to reduce price dispersion, with some platforms even engaging in obfuscation to compensate for increased competition (Ellison and Ellison, 2005; Levin, 2013). In addition, internet ratings, which are supposed to improve information, can be subject to manipulation (Luca and Zervas, 2016). Lastly, information technologies raise privacy concerns which go far beyond economic inquiry. Those issues are particularly sensitive in the context of energy use, which infuses nearly every aspect of everyday life.

information only, and warning to outliers. While feedbacks produce additional energy savings, complete information is found to be a necessary condition for their effectiveness.

7 Conclusion

Energy efficiency can be seen as a credence good, the performance of which is never fully revealed to the buyer. This characteristic is exacerbated by the high upfront costs and multiplicity of stakeholders involved in building investments. As a result, building energy efficiency is subject to an array of information asymmetries, arguably more so than other well-studied credence goods such as medical treatments, taxi rides or auto repair.

In this essay, I reviewed evidence of informational barriers to energy-efficiency investment, with particular attention to whether they qualify as market failures – in the context studied here, information asymmetries – or not – symmetric-information problems. I found that some information barriers are well documented, while others are either inaccurately characterized, not clearly established, or simply overlooked.

I first noted that information relevant to operating energy-consuming assets is incomplete and imperfect in many contexts, with unclear conclusions as to whether information provision improves market outcomes. I then moved to information asymmetries – that is, true market failures – and found them to be more important than previously thought. The longest-studied ones are associated with landlord-tenant relationships. While indistinctly referred to as "split incentives" in the literature, I classified them in three categories: signalling in rental buildings, moral hazard and screening in utility-included rent contracts. All of these are economically important, although they do not seem to induce dramatic over-use of energy. One implication is that banning utility-included contracts could improve social welfare. Another much studied information asymmetry is signalling in building sales, the analysis of which has been facilitated by implementation of energy performance certificates. Here, the conclusion is ambiguous. Prospective buyers seem to respond to information labels, but two counterfactuals are often missing to ascertain that labels operate by elimination of an information asymmetry: what occurs without labels (to identify information levelling), and what occurs with coarser labels (to identify a social-norm effect). Lastly, information asymmetries have been understudied in the context of labour-intensive supply (moral hazard and signalling) and financing (screening, moral hazard and price-quality discrimination) of energy efficiency.

To conclude, it is worth noting that retrofit commissioning occurs very upstream in the production of energy efficiency. Any information asymmetry associated with it might propagate in related transactions, such as building rental and sales. Downstream, on the other hand, financing is somehow the recipient of all other information asymmetries. In the United States alone, the market for energy-efficiency finance is estimated to amount to $100 billion annually (Freehling and Stickles, 2016). More research is therefore needed into these two crucial topics – retrofit commissioning and financing.

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Table 1: Information asymmetries in home energy retrofits

		BUYER/SELLER	OWNER/USER	BORROWER/LENDER
ADVERSE SELECTION	SCREENING		**Suggestive evidence** of incomplete pass-through of energy expenditures onto rents (*3 references*)	**Early evidence** of better loan terms for energy-efficient assets, suggesting no information asymmetry (*1 reference*).
	SIGNALLING	**Compelling evidence of capitalization** of energy savings into home prices, with little evidence of asymmetric information. *(22 references)*	**Compelling evidence of asymmetric information**, owing to several sources of variation: owner-occupied versus rented dwellings; utilities-included versus utilities-excluded rents. *(16 references)*	
PRINCIPAL-AGENT PROBLEMS	MORAL HAZARD	**Scarce evidence in home energy retrofits** (principal is the homeonwer, agent is the contractor). *(1 reference)*	**Compelling evidence of a moderate effect** (on energy savings) in utilities-included rents (principal is the landlord, agent is the tenant) *(6 references)*	**Early evidence** of lower default risk for energy-efficient assets, suggesting no information asymmetry (*3 references*).
	PRICE DISCRIMINATION	**Compelling evidence** of a "distortion at the bottom" in appliance markets (principal is the firm, agent is the consumer) *(3 references)*		Plausible. Not investigated.

Table 2: References associated to Table1

		BUYER/SELLER	OWNER/USER	BORROWER/LENDER
ADVERSE SELECTION	SCREENING		*25, 82, 94*	*9*
	SIGNALLING	*22,34, 38, 39, 43, 48, 50, 51, 52, 57, 60, 70, 73, 74, 80, 91, 93, 96, 98, 115, 121, 122*	*19, 21, 29, 35, 38, 39, 50, 51, 54, 70, 78, 79, 88, 94, 105, 109*	
PRINCIPAL-AGENT PROBLEMS	MORAL HAZARD	*58*	*40, 54, 75, 82, 84, 94*	*9, 77, 99*
	PRICE DISCRIMINATION	*26, 64, 114*		

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