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

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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, borrowers and lenders, and regulators and policy stakeholders. I find evidence of information asymmetries to be compelling in utility-included rental contracts, unclear in home sales and rentals, 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. Another closely related review is that of Matisoff et al. (2016), which covers some of the information asymmetries studied here, though within a broader framework encompassing non-energy impacts of building (e.g., health-related) and resource efficiency in building design, construction, operation and deconstruction. Against this background, my main contribution is to categorize problems that are often referred to with inconsistent terminology[1] and map the available evidence on their significance.

My conclusions are 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 utility-included rental contracts (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. Evidence is also inconsistent in rental housing, where more energy efficient units seem to rent with a premium, yet the market equilibrium is characterized by a relatively poor energy efficiency, as compared to owner-occupied units. Evidence is growing of important information asymmetries in the supply of energy efficiency products (moral hazard, price discrimination). More research is needed on information asymmetries in loan markets, which are key to scaling up energy efficiency. Lastly, some information asymmetries indirectly affect energy efficiency decisions by directly affecting the policies that target them. These have been mainly studied in the context of subsidy programs; much remains to be studied, in particular when it comes to energy performance contracts.

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.

[1] For instance, the notions of "landlord-tenant dilemma" and "split incentives" are commonly used to refer to any problem arising in rental housing. I characterize these problems into three categories: signalling in building rental, screening and moral hazard in utility-included contracts. Likewise, the notion of "credit constraint" is commonly used to refer to any market failure affecting energy efficiency financing. I characterize these into screening and moral hazard in energy efficiency loans. Lastly, the notion of "free riding" is sometimes used in the context of subsidy programs to refer to infra-marginal participants. I stick to the latter designation.

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 discusses information problems that affect policy remedies to the energy efficiency gap. Section 7 puts the findings in perspective and Section 8 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.[2] Though symmetric-information problems are normal 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.[3] 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 covers a bundle of usages. How does more complete information affect market outcomes?

A number of studies have evaluated 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

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[2] 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.
[3] 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).

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.

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 vanishes 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,[4] 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 (2018a) 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

[4] 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.

distribution. In the European Union, a similar experiment was conducted by Andor et al. (2016), who find results similar to Houde (2018a), 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.

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? Available evidence points to 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).[5] 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

[5] 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).

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.

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: Option values

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 energy performance contracts can provide some insurance against the problem, they are subject to some caveats that we discuss in Section 6.2.

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.[6]

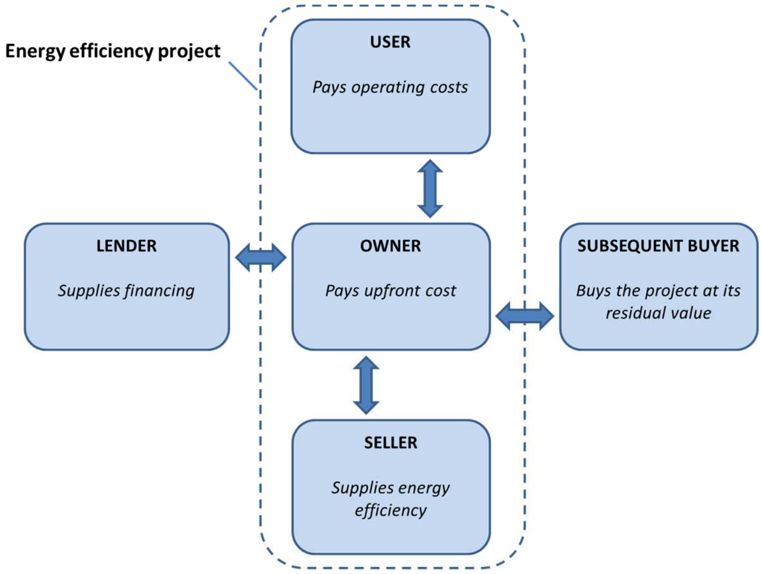

Figure 1: Main stakeholders and contractual relationships in home energy retrofits

Each of these relationships can be subject to a variety of information asymmetries. On top of these relationships, some stakeholders – owners and sellers in particular – can be involved in a relationship with the regulator, or more generally a program administrator, when a policy is implemented. I review below the evidence on the significance of information asymmetries in all of these relationships. 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.

For each relationship, I formulate a null hypothesis corresponding to the absence of any information asymmetry. I examine the validity of each hypothesis and, if rejected, assess the significance of the implied information asymmetry. The findings are summarized in a matrix interacting four types of information asymmetry and three types of relationship (Table 1). Further tables provide methodological detail at the study level.

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 – products that are often referred to as 'lemons.'

[6] 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.

4.1 Imperfect signalling

4.1.1 Building sales

Perhaps the longest-studied information problem associated with energy efficiency is signalling in building sales. If the energy efficiency of a building unit is perfectly observable, we expect the following:

H1: Energy efficiency is capitalized into home prices

The hypothesis started being examined 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; Laquatra, 1986; 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 (2014b) 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. (2015) 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 (2019) finds evidence that changes in relative fuel prices cause changes in relative housing prices in Massachussetts 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 in 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 effectively 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 implementation of any label. 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 restating information decision-makers can anyway gather from observable features.

The most recent studies on the topic are beginning to fill this gap. Exploiting a panel 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 information beyond what is observable without them. Similar conclusions are reached by Fesselmeyer (2018) by exploiting price variation before and after certification in Singapore.[7] In ongoing work, Frondel et al. (2018) 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.

To conclude, existing evidence fails to reject H1 and indicates that the role of energy performance certificates in improving information is modest at best. Energy performance certificates may nevertheless have other effects – behavioural in particular – which remain to be estimated.

4.1.2 Building rental

The question of capitalization similarly applies in rental markets, where by default we expect the following:

H2: Energy efficiency is capitalized into rents

Existing studies tend to confirm H2 – for instance Fuerst and McAllister (2011a, 2011b) and Eichholtz et al. (2010, 2013) in US office buildings, Kok and Jennen (2012) in commercial buildings in the Netherlands, Hyland 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 Brussels in 2001 were positively correlated with the presence of observable features such as 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.

The evidence here suggests that energy efficiency is accurately signalled in rental markets. Yet if it were the case, in equilibrium there should be no difference in energy efficiency between owner-occupied dwellings and rented ones. In other words, H2 implies the following corollary:

H2bis: Owner-occupied dwellings are as energy efficient as are rented ones

Research along this line tends to reject H2bis. Brechling and Smith (1994) find lower ownership of energy-efficient assets in rented properties as compared to 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.

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

(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 therefore paradoxical: Signalling issues do not seem to significantly affect rents, yet the resulting equilibrium is suboptimal. This apparent inconsistency is arguably due to differences in methodological approaches to each fact. One way to reconcile these findings would be to examine how the elasticity of rents paid by tenants compares to that of implicit rents borne by owner-occupiers, both with respect to energy efficiency. A lower elasticity (in absolute value) for tenant's rents would reveal an inability of landlords to fully pass through investment costs onto rents, perhaps due to rigid rent regulations. Lastly, while labels seem to improve decisions, evidence is scarcer as to whether they encourage landlords to initiate energy-efficiency improvements.

4.2 Imperfect screening

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? Under perfect screening, we expect the following:

H3: The rent premium for including utilities covers effective energy usage

The hypothesis 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 in 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 turn over 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 H3 is rejected, with utility-included contracts favouring 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 – subject to some caveats we detail in Section 5.1.1.

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, we therefore expect the following:

H4: Energy efficiency investments carry lower interest rates than do conventional ones

Investigating this hypothesis in commercial mortgages in the United States, An and Pivo (2017) 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. The analysis is however threatened by selection issues, as the authors do not control for borrower characteristics.

Studying personal loans, which is the most commonly adopted tool to finance home energy retrofits, Giraudet et al. (2019) reach opposite findings in France. Using a unique dataset of posted interest rates collected from credit institutions' websites, the authors circumvent the selection issues faced by An and Pivo (2017) in that their data do not depend on either borrower or loan contract characteristics. They find that, on average, home retrofits are priced at a higher rate than otherwise conventional investment (automobiles in particular), and even more so when home retrofits include energy efficiency improvements. A tentative explanation is that lenders use the loan project as a screening device of the borrower's wealth in an attempt to extract surplus. This can cause credit rationing and therefore too little investment in home energy retrofits.

The evidence on whether screening problems affect energy efficiency loans is therefore mixed.

5 Principal-agent problems

Principal-agent problems arise in situations where 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

Utility-included contracts can be seen as a relationship between a principal – the utility – and an agent – the occupant. This relationship can be affected by incentive problems, which add up to the selection issues studied in section 4.2.1. If utilities could perfectly monitor occupants' behaviour and charge them accordingly, we would expect the following:

H5: Occupants use as much energy under utility-included contracts as under individual billing

Yet in practice, occupants' behaviour is hard to observe, either because it cannot be monitored in real time or because it is pooled with others' behaviour under shared billing in multi-family housing. Such situations are conducive to moral hazard and thus rejection of H5: 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.

H5 is rejected in all studies that I am aware of that investigate it. Using RECS data, Levinson and Niemann (2004) find that US households use slightly more energy under such contracts. Maruejols and Young (2011) find similar effects in Canada. Gillingham et al. (2012) similarly find that under such contracts, occupants in California are 16% more likely to change the 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 up to four years 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 of moral hazard in utility-included contracts is therefore 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. This recommendation is however subject to some caveats. First, the benefits from the ban must be weighed against the cost of installing individual meters. Second, they must also be weighed against forgone benefits, as utility-included contracts can enable landlords to attract certain tenants whose profile they particularly value (Choi and Kim, 2012). Third, banning utility-included contracts can give rise to heating externalities in multi-family housing. Indeed, because of heat transfers within buildings, especially along the vertical gradient, some occupants may 'free ride' by turning down their thermostat as they get heat from an adjacent dwelling; this in turn induces their neighbor to turn their thermostat up to enjoy their desired level of comfort. By reducing the marginal cost of changing thermostat settings to zero, utility-included contracts remove these incentives. To the best of my knowledge, however, such externalities have never been discussed nor quantified.

5.1.2 Building retrofits

An important relationship in the energy retrofit picture is that between a contractor – the agent – and an investor – the principal. In practice, 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 quality in the installation tasks performed by contractors. In the absence of the problem, we expect the following:

H6: Contractors put identical effort into observable and unobservable energy efficiency tasks

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. Interestingly, the fact that quality is underprovided on certain, but not all, days of the week suggests that some incentives exist to provide quality, perhaps in the form of reputational returns. Based on the only existing study, we can only conclude that evidence on H6 is mixed.

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 raises interesting incentive problems that are further discussed in Section 6.2.

5.1.3 Energy-efficiency loans

As stated earlier, energy efficiency is supposed to reduce default risk in associated loans (where the borrower can be seen as the agent and the lender the principal). In well-functioning credit markets, we thus expect the following:

H7: Borrowers default less when borrowing to save energy

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 (2017) 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 confirm H7, which 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

Energy efficiency is essentially a characteristic of energy-using assets and, as such, it can be provided in various degrees. In other words, the seller of energy-using products typically sells a menu of products of differing energy efficiency. If such markets function well, we expect the following:

H8: Producers offer consumers their optimal level of energy efficiency

This hypothesis can however be rejected if price discrimination – also known as monopolistic screening – occurs. This is typically the case 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 under-provide quality at the low-end of the product line so as to maintain high mark-ups on the sales of high-end products (Mussa and Rosen, 1978). If 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).[8] Houde (2018b) 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. The scarce available evidence therefore suggests that H8 is rejected.

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[8] 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 an excess of it (Plourde and Bardis, 1999).

While there is no direct way to solve the problem, partial solutions exist. First and foremost, anti-trust remains the main policy tool to limit the deadweight loss of imperfect competition. In this regard, it is worth mentioning that the French Anti-trust authority ruled against high concentration levels in the heating, air conditioning and hot water industry.[9] Second, when energy efficiency investments are targeted by public subsidy programs, the regulator can address the distortions due to price discrimination by carefully adjusting subsidy regimes, for instance by offering more generous subsidies for low-end products than for high-end ones (Nauleau et al., 2015). Despite restoring efficiency in the provision of quality, this approach raise equity concerns in that it compensates energy efficiency suppliers for the deadweight loss they otherwise cause.

6 Policy-induced information asymmetries

So far we have examined information problems that directly affect energy efficiency decisions, assuming away further policy-induced effects. In practice, however, energy efficiency decisions are targeted by an array of policies meant to correct the multiple market failures they are associated with – chiefly energy-use externalities, but also the very information asymmetries that are at the core of this paper. These policies may in turn create information asymmetries between the regulator and some stakeholders – program participants and intermediaries such as retrofit contractors in particular. Let us review here the evidence on how these information asymmetries affect policy effectiveness.

6.1 Imperfect screening in subsidy programs

The most common policy tool to promote energy efficiency is subsidy programs. Primarily motivated by reducing energy-use externalities, these programs are either directly administered by governments (e.g., tax credits, zero-interest loans) or rolled out by electric and gas utilities to comply with so-called energy saving obligations or demand-side management programs.[10]

A regulator willing to minimize the cost of subsidy programs would do as follows:

H9: Regulators optimally screen out infra-marginal participants in subsidy programs

In practice, program administrators cannot observe the participants' willingness to invest without the subsidy; as a result, they may give subsidies to households who would have invested anyway. Note that the problem affects all subsidy programs and has little to do with the credence good nature of energy efficiency. Yet the evidence is compelling that it is significant in this context. With varying geographical scope and methodology, existing studies point to non-additional (or infra-marginal) participants typically accounting for 50%, and not infrequently up to 90%, of total participants (Joskow and Marron, 1992; Hassett and Metcalf, 1995; Malm, 1996; Grösche and Vance, 2009; Boomhower and Davis, 2014; Nauleau, 2014; Alberini et al., 2016; Rivers and Shiell, 2016; Houde and Aldy, 2017; Collins and Curtis, 2018).[11] The welfare consequences of the problem are not clear when

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[9] Conseil de la Concurrence, 2006. Décision no. 06-D-03 bis du 9 Mars 2006 Relative à des Pratiques Mises en Oeuvre Dans le Secteur des Appareils de Chauffage, Sanitaires, Plomberie, Climatisation.

[10] The relationship between the regulator and utilities in the context of energy saving obligations also raises interesting incentive problems (Lewis and Sappington, 1992; Wirl, 1995) that are out of the scope of this paper.

[11] The problem is generally difficult to empirically quantify, for lack of a counterfactual benchmark without subsidies. In this regard, the most credible approaches are those based on difference-in-differences (Alberini et al., 2016; Houde and Aldy, 2017) and regression discontinuity (Boomhower and Davis, 2014) designs. The fact that less credible approaches produce similar estimates confirms the significance of the screening problem.

different options of varying energy efficiency are eligible in the program. Then, non-additional participants can opt for a higher efficiency option than that which they would have otherwise purchased. Although the impact of subsidies has been less studied on the intensive margin of investment than that on the extensive one, preliminary evidence suggests it is small on the former (Rivers and Shiell, 2016; Houde and Aldy, 2017). Overall, H9 is clearly rejected and screening issues therefore seem to significantly raise the public cost of energy efficiency subsidy programs.

Solutions start being discussed to address the problem. Globus-Harris (2018) proposes to introduce a waiting period between application to the program and investment. By exploiting the fact that, unlike additional participants, non-additional ones are sensitive to time delays, the mechanism can help the regulator screen out non-additional participants. Its effectiveness is found to depend on the waiting period and the applicants' impatience. This solution remains to be tested in the field.

6.2 Moral hazard in subsidy programs and energy performance contracts

Many policies can be seen as a principal-agent relationship between the regulator – the principal – and some stakeholders – the agent, e.g., program participants, contractors. In this context, incentive problems can arise from poor policy design. Under perfect monitoring and verification, they should not affect policy outcomes, so that:

H10: Stakeholders do not respond to misplaced incentives stemming from poor policy design

How does this prediction fare in programs that give rise to misplaced incentives? One such program is that studied by Blonz (2019) in California. In this subsidy program, electric utilities hire agents to perform two tasks: conduct an audit to determine the eligibility of an energy efficiency measure, and install the measure if eligible. Blonz (2019) identifies moral hazard by exploiting variation between two forms of contract: one in which each task is performed by a different contractor and another one in which both are performed by one and the same contractor. The author finds that the latter contract induces contractors to misreport non-eligible measures as eligible in an attempt to get the reward from subsequently installing it. The problem seriously undermines the environmental effectiveness of the policy and annihilates its social benefits. Interestingly, this study led the utility to ban 'two-task' contracts.

Another important energy efficiency policy where misplaced incentives can be relevant is energy performance contracting. Under such contract, a retrofit contractor typically guarantees to the building manager that energy consumption after retrofit will not exceed a certain level. The instrument is specifically meant to address informational barriers to energy efficiency improvements, in particular the moral hazard problem discussed in Section 5.1.2, which can be exacerbated by the information imperfections discussed in Section 2.2. Energy performance contracts are routinely offered by energy service companies in the industrial and commercial sectors (Vine, 2006). They are much less common in the residential sector.

By addressing one form of moral hazard, energy performance contracts may have the unintended effect of raising another moral hazard. Just as the contractor's effort is unobservable, so too is the energy user's behaviour. In this informational context, having the contractor guarantee her energy consumption gives the energy user an incentive to over-consume – an incentive similar to that associated with utility-included contracts. Through calibrated simulations building up on their empirical analysis of a utility-sponsored retrofit program, Giraudet et al. (2018) suggest that the deadweight loss associated with this form of moral hazard reduces the efficiency of energy performance contracts, in particular relative to other forms of regulation such as certification of professional contractors. Note that this second moral hazard is only relevant when the building manager and the energy user are one and the same person, which is typically the case in owner-occupied dwellings. This can explain why energy performance contracts are so scarce in the residential sector.

The scant available evidence so far suggests that, when relevant, H10 is rejected.

7 Discussion

7.1 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 an 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. In more recent work, Astier (2018) 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, information only, and warning to outliers. While feedbacks produce additional energy savings, complete information is found to be a necessary condition for their effectiveness.

7.2 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.

8 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, or 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 reviewed ten possible sources of information asymmetries – that is, true market failures – and found different degrees of significance. The longest-studied problems are those potentially occurring in 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. I found evidence on the first problem to be inconsistent, as the capitalization of energy efficiency observed does not seem to be reflected in the market equilibrium. In constrast, I found compelling evidence of moral hazard and screening problems in utility-included rent contracts, which however does not seem to induce dramatic over-use of energy. One implication is that banning utility-included contracts could improve social welfare, though this recommendation must be weighed against forgone benefits that remain to be quantified. 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 clearly respond to information labels, but two counterfactual benchmarks are often missing to ascertain that labels operate by elimination of an information asymmetry: what occurs without labels (in order to identify information levelling), and what occurs with coarser labels (in order to identify a social-norm effect). Information asymmetries have been understudied in the context of labour-intensive supply (moral hazard and price discrimination) and financing (screening and moral hazard) of energy efficiency. Lastly, policy experiments could be conducted to test the promising solutions that are being proposed to overcome the information asymmetries affecting energy efficiency policies.

To conclude, it is worth noting that the procurement of retrofits to building contractors occurs very upstream in the production of energy efficiency. Anticipating the moral hazard problem discussed in this paper (cf. Section 5.1.2), it might be difficult for a building manager to hire a diligent contractor. This screening problem is unexplored. Yet if confirmed, 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 procurement and financing.

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Table 1: Summary of the evidence on information asymmetries in home energy retrofits

		BUYER/SELLER	OWNER/USER	BORROWER/LENDER	REGULATOR/STAKEHOLDER
ADVERSE SELECTION	IMPERFECT SCREENING		*H3: The rent premium for including utilities covers effective energy usage* **Rejected** in 100% of the material reviewed (3 studies, §4.2.1)	*H4: Energy efficiency investments carry lower interest rates than do conventional ones* **Mixed:** rejected in 50% of the material reviewed (2 studies, §4.2.2)	*H9: Regulators optimally screen out infra-marginal participants in subsidy programs* **Rejected** in at least 90% of the material reviewed (10 studies, §6.1)
	IMPERFECT SIGNALLING	*H1: Energy efficiency is capitalized into home prices* **Not rejected** in 83% of the material reviewed (24 estimates out of 29). **Additional finding**: 6 studies suggest this is the case even in the absence of energy efficiency labels (§ 4.1.1)	*H2: Energy efficiency is capitalized into rents* **Not rejected** in 88% of the material reviewed (7 studies out of 8). *H2bis: Owner-occupied dwellings are as energy efficient as are rented ones* **Rejected** in 100% of the material reviewed (6 studies). (§ 4.1.2)		
PRINCIPAL-AGENT PROBLEMS	MORAL HAZARD	*H6: Contractors put identical effort into observable and unobservable energy efficiency tasks* **Partially rejected** in one study finding evidence of moral hazard 20% of the time (specifically on Fridays). (§5.1.2.)	*H5: Occupants use as much energy under utility-included contracts as under individual billing* **Rejected** in 100% of the material reviewed (6 studies, §5.1.1)	*H7: Borrowers default less when borrowing to save energy* **Not rejected** in 100% of the material reviewed (2 studies, §5.1.3) **Qualification**: studies subject to selection issues	*H10: Stakeholders do not respond to misplaced incentives stemming from poor policy design* **Rejected** in one study examining the role of auditors in a subsidy program (§6.1)
	PRICE DISCRIMINATION	*H8: Producers offer consumers their optimal level of energy efficiency* **Rejected** in 100% of the material reviewed (3 studies, §5.2)			

Table 2: Evidence on imperfect signalling in building sales (contains 29 estimates from 21 studies)

H1 ***Energy efficiency is capitalized into home prices***

Reference	**Geographical scope**	**Sectoral scope**	**Fuel type**	**Energy usage**	**Sample size**	**Method**	**Model**	**Time period**	**Hypothesis validated**	**Certificate program**	**Comments**
Brounen and Kok (2011)	The Netherlands	Commercial and Residential: Apartment, Detached, Duplex, Semi-detached	NA	Heating	31,993		Heckman two-step estimation	January 2008 - August 2009	Yes	EU-EPC	
Dinan and Miranowski (1989)	Des Moines, Iowa, US	Residential: Detached dwellings	Natural gas, other	Heating	234		Hedonic model	January – June 1982	Yes		
Eichholtz et al. (2013)	US	Commercial: Office buildings	NA	NA	5,993	GLS		2009	Yes	Energy Star, LEED	
Eichholtz et al. (2010)	US	Commercial: Office buildings	NA	NA	199 in treatment group, 1,614 in control group	Diff-in-diff		2004-2007	Yes	Energy Star, LEED	Green dwellings display a 16% sales premium.
Fesselmeyer (2018)	Singapore	Residential: Apartments	NA	NA	119,826	Diff-in-diff		2005-2016	Yes	Green Mark Scheme	The price premium is not caused by the energy label.
Frondel et al. (2018)	Germany	Residential: Single-family and multi-family dwellings	NA	NA	412,637	Diff-in-diff	Fixed effects	2013-2015	Yes	EU-EPC	Upon disclosure of energy efficiency information, low-quality dwellings experience the largest price reductions.
Fuerst and MacAllister (2011a)	US	Commercial: Office buildings	NA	NA	6,157		Hedonic model	1999-2008	Yes	Energy Star, LEED	Sales premium of 25% and 26%, for LEED and Energy Star certified dwellings, respectively.
Fuerst and MacAllister (2011b)	UK	Commercial: Retail, office, industrial	NA	NA	606		Hedonic model	April 2011	No	EU-EPC	Small sample size
Fuerst et al.	UK	Residential: Detached	NA	NA	16,653		Hedonic	1995-	No	EU-EPC	Rural, small sample, R sq = 0.47

(2015)		dwellings in sparsely populated areas					model	2012			
Fuerst et al. (2015)	UK	Residential: Detached dwellings in densely populated areas	NA	NA	68,354		Hedonic model	1995-2012	Yes	EU-EPC	Densely populated areas
Fuerst et al. (2015)	UK	Residential: Semi-detached dwellings	NA	NA	106,793		Hedonic model	1995-2012	Yes	EU-EPC	
Fuerst et al. (2015)	UK	Residential: Terraced dwellings	NA	NA	115,658		Hedonic model	1995-2012	Yes	EU-EPC	
Fuerst et al. (2015)	UK	Residential: Apartments	NA	NA	25,637		Hedonic model	1995-2012	Yes	EU-EPC	
Harjunen and Liski (2014)	Finland	Residential: Single-family detached dwellings	District heating	Heating	1,868			2001-2012	Yes		More energy efficient heating technologies are capitalized in house prices (district heating as opposed to electricity)
Hyland et al. (2013)	Ireland	Residential: Detached, semi-detached, terraced, apartment	NA	NA	15,060	Heckman selection		January 2008 - March 2012	Yes	BER	Sales premium for A-rated dwellings is 9%.
Johnson and Kaserman (1983)	Tennessee, US	Residential: Detached dwellings	Electricity, natural gas	Heating	1,317	IV, 2SLS	Hedonic model	1978	Yes		
Kahn and Kok (2014)	US	Residential: Single-family dwellings	NA	Cooling	4,321 in treatment group; 1,600,558 in control group		Hedonic model	2007-2012	Yes	Energy Star, LEED, GreenPoint	
Laquatra (1986)	Minnesota, US	Residential: Detached dwellings	NA	NA	81	IV	Hedonicprice index	1981-1982	Yes		Low sample size. Data subsequently used by Gilmer (1989) to calibrate a search model

Murphy (2014b)	The Netherlands	Residential: Apartment, detached, 2 under 1 roof, corner, terraced, other	NA	NA	297 in treatment group; 1,027 in control group	Diff-in-diff, Pearson's chi-squared			No	EU-EPC	Based on surveys, pre and post-purchase. The label had little impact in price negotiations on house sale whereas a third of the label owners stated that they applied for EPC in order to increase the market value of their property.
Myers (2019)	Massachusetts, US	Residential: Single-family dwellings	Heating oil, natural gas	Heating	528,642	IV, 2SLS		1990-2011	Yes		Relative fuel price has an effect on relative transaction price
Nevin and Watson (1998)	US	Residential: Single-family detached and attached dwellings	Electricity, piped gas	Heating	14,400*	IV	Hedonic model	1991-1996	Yes		Laquatra et al. (2002) object that according to Nevin and Watson's data, house values decrease with dropping utility bills
Nevin and Watson (1998)	US	Residential: Single-family attached and detached dwellings	Fuel oil	Heating	*	IV	Hedonic model	1994-1996	Yes		Laquatra et al. (2002) object that according to Nevin and Watson's data, house values decrease with dropping utility bills.
Nevin and Watson (1998)	US	Residential: Single-family detached dwellings	Fuel oil	Heating	*	IV	Hedonic model	1991-1993	No		Small sample size. Due to a sharp increase in fuel oil prices following the invasion of Kuwait, a significant number of households shifted to alternative heating fuels. The authors suggest that the positive relation between the heating expenditure and home values in that period could be due to a large proportion of households reporting high fuel expenditures following the spike, and property values that reflect the future value after the planned energy conversion works.
Olaussen et al. (2017)	Oslo, Norway	Residential: Single-family houses, Apartments, Townhouses, Semi-detached houses	NA	NA	4,674		Fixed effects	2000-2014	No	EU-EPC	There price premium is not caused by the energy label.
Stanley et al. (2016)	Dublin area, Ireland	Residential: Apartments, Detached, Terraced, End-	NA	NA	2,792		Hedonic regression	January 2009 - June 2014	Yes	BER	

		of-terrace, Semi-detached									
Wahlström (2016)	Sweden	Residential: Single-family dwellings	Electricity, district heating, heat pump, biofuels, oil-fired boiler, other	Heating, cooling	77,000	OLS	Hedonic model	2009-2010	Yes	EU-EPC	The results indicate a strong willingness to pay for housing attributes that reduce energy consumption. The EPC itself is not a variable in the regression.
Walls et al. (2017)	Austin, US	Residential: Single-family dwellings	NA	NA	42,600		Hedonic regression, multiple matching procedures	2008-2011	Yes	Energy Star, local certifications	
Walls et al. (2017)	Portland, US	Residential: Single-family dwellings	NA	NA	117,828		Hedonic regression, multiple matching procedures	2005-2011	Yes	Energy Star, local certifications	In Portland, the premium is exceeding the actual energy saving.
Walls et al. (2017)	the Research Triangle region in North Carolina, US	Residential: Single-family dwellings	NA	NA	16,041		Hedonic regression, multiple matching procedures	2009-2011	Yes	Energy Star, local certifications	

Table 3: Evidence on imperfect signalling in building rental – rent premium (9 studies)

H2	***Energy efficiency is capitalized into rents***										
Reference	**Geographical scope**	**Sectoral scope**	**Fuel type**	**Energy usage**	**Sample size**	**Method**	**Model**	**Time period**	**Hypothesis validated**	**Certificate program**	**Comments**
Bala et al. (2014)	Brussels region, Belgium	Residential	NA	NA	507,868	Two-step estimation procedure with locational fixed effects	Hedonic model	2001	Yes		
Dressler and Cornago (2017)	Brussels region, Belgium	Residential	NA	NA	13,586	IV	Hedonic model	January 2010 – September 2014	Yes	EU-EPC	Owners with less energy-efficient EPC ratings tend to hide this information
Eichholtz et al. (2013)	US	Commercial: Office buildings	NA	NA	20,801	GLS	Energy Star, LEED	2009	Yes		
Eichholtz et al. (2010)	US	Commercial: Office buildings	NA	NA	7,920	OLS	Energy Star, LEED	2004-2007	Yes		Green dwellings display a 3% rental premium.
Fuerst and MacAllister (2011a)	US	Commercial: Office buildings	NA	NA	10,970		Hedonic model	1999-2008	Yes	Energy Star, LEED	Rental premium of 5% and 4%, for LEED and Energy Star certified dwellings, respectively.
Fuerst and MacAllister (2011b)	UK	Commercial buildings: Retail, office, industrial	NA	NA	606		Hedonic model	April 2011	No	EU-EPC	Dependent variable : Market rent ; Small sample size
Hyland et al. (2013)	Ireland	Residential: Detached, Semi-detached, Terraced, Apartment	NA	NA	20,825	Heckman selection		January 2008 - March 2012	Yes	BER	Rent premium for A-rated dwellings is approximately 2%.
Kok and Jennen (2012)	the Netherlands	Commercial: Office buildings	NA	NA	1,100		Hedonic model	2005-2010	Yes	EU-EPC	D to G rated office buildings receive 6.5% lower rent than A to C rated buildings.

Reichardt (2018)	Central and Eastern US	Office buildings	NA	NA	4,217	Propensity-weighted regression	Log-linear hedonic model	Yes	Energy Star, LEED

Table 4: Evidence on imperfect signalling in building rental – market equilibrium (7 studies)

H2bis ***Owner-occupied dwellings are as energy-efficient as are rented ones***

Reference	Geographical scope	Sectoral scope	Fuel type	Energy usage	Sample size	Method	Model	Time period	Hypothesis validated	Certificate program	Comments
Brechling and Smith (1994)	UK	Residential: Semi-detached, terraced dwellings, apartments	NA	NA	6,395		Logit Reduced-Form	1986	No		Lower prevalence of loft insulation, wall insulation, double glazing
Davis (2012)	US	Residential	NA	Household appliances : refrigerators, clothes washers, dishwashers, lighting	Owners: 2979, renters: 1219		Linear probability model	2005	No	Energy Star	Tenants are less likely to report owning energy efficient household appliances (5.6% for refrigerators, 8.6% for dishwashers, 2.7% for clothes washers).
Gillingham et al. (2012)	California, US	Residential: single-family houses, townhouses, apartments		Heating, cooling	20,933	Maximum likelihood	Ordered probit model	2003	No		Owner-occupied dwellings are 20% more likely to be insulated in the attic or ceiling and 13% in exterior walls.
Krishnamurthy and Kriström (2015)	Australia, Canada, Chile, France, Israel, South Korea, Japan, the Netherlands, Spain, Sweden, Switzerland	Residential	NA	NA	9,432		Probit, Logit model	2011	No		Owners are 45% more likely to have energy-efficient appliances and 2% more likely to have solar panels.
Melvin (2018)	US	Residential	NA	Heating, cooling, other	11,498		Logit, Probit, Linear Probability Model	2009	No		Rented dwellings less energy-efficient when it comes to space-heating, water-heating, window thickness, insulation and weatherization.
Myers (2015)	Northeastern US	Residential	Heating oil, natural gas	Heating	6,163	Fixed effects regression		2005-2009	No		
Scott (1997)	Ireland	Residential	NA	NA	1,200	Logistic		November	No		

						regression		1992			

Table 5: Evidence on imperfect screening in utility-included contracts (3 studies)

H3	*The rent premium for including utilities covers effective energy usage*										
Reference	**Geographical scope**	**Sectoral scope**	**Fuel type**	**Energy usage**	**Sample size**	**Method**	**Model**	**Time period**	**Hypothesis validated**	**Certificate program**	**Comments**
Choi and Kim (2012)	21 metropolitan area in the US	Residential	NA	Heating, cooling, other	4,895	Logit estimation	Hedonic model	2000-2002	No		Utilities-included dwellings let out for higher rents than comparable metered dwellings
Levinson and Niemann (2004)	148 metropolitan areas in the US	Residential: Apartments	Natural gas, fuel oil, electricity, liquefied propane gas	Heating	31,293	OLS		1985-1997	No		
Myers (2015)	Northeastern US	Residential	Heating oil, natural gas	Heating	6,163	Fixed effects regression		2005-2009	No		

Table 6: Evidence on imperfect screening in energy-efficiency loans (2 studies)

H4	***Energy efficiency investments carry lower interest rates than do conventional ones***										
Reference	**Geographical scope**	**Sectoral scope**	**Fuel type**	**Energy usage**	**Sample size**	**Method**	**Model**	**Time period**	**Hypothesis validated**	**Certificate program**	**Comments**
An and Pivo (2017)	US	Commercial (Office buildings)	NA	NA	6,304		Logit model	2000-2013	Yes	LEED, Energy Star	Energy efficiency investments display better loan terms if they were certified green at loan origin.
Giraudet et al. (2019)	France	Residential	NA	NA	240,962	OLS		2015-2016	No		Based on posted interest-rate data

Table 7: Evidence on moral hazard in utility-included contracts (6 studies)

H5 ***Occupants use as much energy under utility-included contracts as under individual billing***

Reference	Geographical scope	Sectoral scope	Fuel type	Energy usage	Sample size	Method	Model	Time period	Hypothesis validated	Certificate program	Comments
Elinder et al. (2017)	Sweden	Residential: apartments	NA	NA	800 in treatment group, 1000 in control group	Diff-in-diff		January 1, 2007 – December 31, 2015	No		Tenants reduce their energy consumption while switching from landlord-pay to tenant-pay regime.
Gillingham et al. (2012)	California, US	Residential: single-family houses, townhouses, apartments	NA	Heating, cooling	20,933	Maximum likelihood	Ordered probit model	2003	No		Tenants in tenant-pay regimes more likely to reduce heating during night.
Kahn et al. (2014)	US	Commercial	Electricity	NA	3521		Fixed effects model	2009	No		Energy consumption is higher in buildings where the tenants are not impacted by marginal cost of energy consumption.
Levinson and Niemann (2004)	148 metropolitan areas in the US	Residential: Apartments	Natural gas, fuel oil, electricity, liquefied propane gas	Heating	31,293	OLS		1985-1997	No		
Maruejols and Young (2011)	Canada	Residential: multi-family dwellings	Electricity, natural gas, oil	Space heating, hot water	4,551	Least squares regression		2003	No		
Myers (2015)	Northeastern US	Residential	Heating oil, natural gas	Heating	6,163	Fixed effects regression		2005-2009	?		

Table 8: Evidence on moral hazard in home energy retrofits (1 study)

H6	*Retrofit contractors put identical effort into observable and unobservable energy efficiency tasks*										
Reference	**Geographical scope**	**Sectoral scope**	**Fuel type**	**Energy usage**	**Sample size**	**Method**	**Model**	**Time period**	**Hypothesis validated**	**Certificate program**	**Comments**
Giraudet et al. (2018)	Florida, US	Residential dwellings	Electricity and natural gas	NA	2,936	Diff-in-diff		2006-2012	No		Moral hazard only occurs on Fridays. It contributes to 70% of the discrepancy between predicted and realized savings.

Table 9: Evidence on moral hazard in energy-efficiency loans (2 studies)

H7	*Borrowers default less when borrowing to save energy*										
Reference	**Geographical scope**	**Sectoral scope**	**Fuel type**	**Energy usage**	**Sample size**	**Method**	**Model**	**Time period**	**Hypothesis validated**	**Certificate program**	**Comments**
An and Pivo (2017)	US	Commercial (Office buildings)	NA	NA	6,304		Logit model	2000-2013	Yes	LEED, Energy Star	Energy efficiency investments carry lower default risk.
Kaza et al. (2014)	US	Residential: single-family owner-occupied houses	NA	NA	24,944 in treatment group, 46,118 in control group	Diff-in-diff	Multinomial Logit model	2002-2010	Yes	Energy Star	Mortgages on Energy Star houses are one-third less likely to default.

Table 10: Evidence on price-discrimination in energy-efficiency product lines (3 studies)

H8	*Producers offer consumers their optimal level of energy efficiency*										
Reference	**Geographical scope**	**Sectoral scope**	**Fuel type**	**Energy usage**	**Sample size**	**Method**	**Model**	**Time period**	**Hypothesis validated**	**Certificate program**	**Comments**
Cohen et al. (2017)	UK	Household appliances : refrigerators	Electricity	Refrigerators	2,421	2SLS	Discrete-choice demand model, nested logit model	2002-2007	No		Consumers undervalue future energy costs by 35%.
Houde (2018b)	US	Household appliances : refrigerators	Electricity	Refrigerators	2,752	Diff-in-diff		January 2007 – December 2008	No	Energy Star	Products with environmental certifications are not only more expensive due to a higher cost for producing energy-efficient technology but producers also charge a higher premium for the label itself.
Spurlock (2013)	US	Household appliances : clotheswashers	Electricity	Clothes washers	699 in treatment group, 1,415 in control group	Diff-in-diff		2003-2007	No	Energy Star	Clothes washer prices dropped within-model after 2004 and 2007 energy efficiency standard changes.

Table 11: Evidence on imperfect screening in subsidy programs (10 studies)

H9	*Regulators optimally screen out infra-marginal participants in energy efficiency subsidy programs*										
Reference	**Geographical scope**	**Sectoral scope**	**Fuel type**	**Energy usage**	**Sample size**	**Method**	**Model**	**Time period**	**Hypothesis validated**	**Certificate program**	**Comments**
Alberini et al. (2016)	Maryland, US	Residential	Electricity	NA	108,387	Diff-in-diff-in-diff		2008-2012	No		Data displayed high levels of heat pump usage prior to its replacement which suggests that the incentives are used for cases where the appliances would be replaced in the absence of incentives.
Boomhower and Davis	US	Residential	Electricity	Appliances : refrigerators	237,552	RD		May 2009-	No		More than two-thirds of participants are inframarginal and approximately

(2014)				and air-conditioners				April 2011		50% of all participants would have replaced their appliances without any subsidy offered.
Collins and Curtis (2018)	Ireland	Residential	NA	NA	28,454	OLS		June 2010 – July 2016	No	7% of inframarginal participants
Grösche and Vance (2009)	Western Germany	Residential: single-family dwellings	NA	NA	21,28		Error components logit model	2005	No	Around 50% of inframarginal participants
Hassett and Metcalf (1995)	US	Residential	NA	NA	74,792	Logit fixed effects	Discrete choice model	1979-1981	?	Inframarginal participation is not directly quantified. Evidence that participants are not strategically delaying conservation investment
Houde and Aldy (2017)	US	Residential	Electricity	Appliances : refrigerators, clothes washers, dishwashers	37,150	Diff-in-diff		January 2008 – November 2012	No	70% of inframarginal participants
Joskow and Marron (1992)	US	Residential and commercial	Electricity					1991	No	
Malm (1996)	US	Residential		Heating					No	89% of participants are considered inframarginal although the figure might be an overestimation given the lack of exact definition of 'highly energy-efficient' among respondents
Nauleau (2014)	France	Residential	Electricity, gas, fuel		36,367		Random effect dichotomous logit model	2002-2011	No	40-85% of inframarginal participants after 2006
Rivers and Shiell (2016)	Canada	Residential	Natural gas	Heating	328,688		Nested logit estimation, weighted exogenous sample maximum likelihood	1 April 2007 – 31 March 2011	No	50% of inframarginal participants in the subsidy and tax credit programs

Table 12: Evidence on moral hazard in subsidy programs and energy performance contracts (2 studies)

H10	***Stakeholders do not respond to misplaced incentives stemming from poor policy design***										
Reference	**Geographical scope**	**Sectoral scope**	**Fuel type**	**Energy usage**	**Sample size**	**Method**	**Model**	**Time period**	**Hypothesis validated**	**Certificate program**	**Comments**
Blonz (2019)	California, US	Residential	Electricity	Appliances : Refrigerators	271,126			January 2009 – September 2012	No		Contractors misreported data for 19% and 7.8% of households, for an average incentive of $123 ('integrated-task') and $25 ('separated-task') per report, respectively.
Giraudet et al. (2018)	Florida, US	Residential dwellings	NA	NA	2,936	Diff-in-diff		2006-2012	N/A		Numerical simulations suggesting that consumer moral hazard could significantly undermine the efficiency of energy savings insurance