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Asymmetric information on the market for energy efficiency: Insights from the credence goods literature*

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Abstract

Imperfect information is widely acknowledged to hamper the adoption of energy efficient technologies. In this paper, we study supply-side implications of the associated incentive structure. We build on existing evidence suggesting that energy efficiency owns a credence component, whereby the supply side of the market has more information about what technology is best for consumers. The literature on credence goods markets suggests that informational advantage by an expert-seller leads to market inefficiencies, including low trade volume. We start by developing a simple framework to study supply-side incentives related to the provision of energy efficient technologies. We then document inefficiencies and potential remedies by discussing linkages between an empirical literature on credence goods and that on the market for energy efficiency. Doing so, we identify policy implications and research gaps that are relevant for the adoption of energy efficiency technologies.

Keywords: Energy efficiency; Asymmetric information; Credence goods; Energy policy; Environmental externalities; Technology adoption.

JEL Codes: D18; D82; H23; Q41.

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1 Introduction

Energy is consumed for the services it provides, and consumers need a technology to transform energy into these services. Energy efficiency measures how much of these valuable services can be obtained for a given unit of energy input. It follows that, by adopting more efficient energy technologies, consumers can potentially lower energy use without affecting the level of service they consume.[1] Because of externalities associated with energy use, and in particular fossil resources that contribute to both local (e.g. airborne particulate matter) and global (e.g. carbon dioxide) emissions, many countries actively promote the adoption of energy efficient technologies in order to reduce energy consumption (Gillingham et al., 2016). As highlighted by Allcott and Greenstone (2012), these policies ought to target inefficiencies on the market for energy technologies. The existing literature emphasizes informational failure that affect investment behavior, including imperfect information about and inattention to future energy savings (see also Gerarden et al., 2017).

We argue that the supply-side of the market for energy technology holds relevant information and may have little incentives to share it with consumers. Based on this observation, this paper focuses on supply-side incentives associated with the asymmetric information on the market for energy technologies and implied market inefficiencies. As initially put forward by Sorrell (2004) and recently discussed by Giraudet (2018) and Plambeck and Taylor (2019), consumers do not directly observe the level of energy efficiency of alternative technologies, and they are therefore unable to gauge whether a technology meets their needs both before and after the purchase/installation. One implication is that consumers need to rely on information provided by the supply-side of the market in order to identify which option is best suited for their needs (this is also discussed in Allcott and Sweeney, 2017; Allcott and Greenstone, 2017). In turn, the fact that the supply-side of the market possesses an informational advantage implies that the market for energy efficient technologies inherits the properties and inefficiencies of markets for

[1] Note that energy efficiency improvements reduce the relative price of energy services, which may lead to an increase in the demand for these services. Therefore, improving energy efficiency does not imply a one-to-one reduction of energy consumption (see Chan and Gillingham, 2015).

credence goods.[2]

In Section 2 we start by considering energy efficiency investment decisions in relation to the basic credence goods model of Dulleck and Kerschbamer (2006). This framework allows us to identify sources of inefficiencies associated with credence goods, and discuss "baseline" results from the seminal implementation of credence good markets in the laboratory by Dulleck et al. (2011). In the next step, we relate the framework of Dulleck and Kerschbamer (2006) to the simple model for energy efficiency investments by Allcott and Greenstone (2012), clarifying which aspects of investment decisions are likely to be affected by informational asymmetries. This endeavor delivers the main contribution of this work, namely identifying how inefficiencies studied in the credence goods literature translate in the context of energy efficiency investment decisions, and how the credence component of energy-using technologies can affect market efficiency.

Conceptually, the credence goods framework provides a supply-side perspective on the observed tendency of consumers invest "too little" in energy efficiency, seemly failing to realize financial benefits from energy savings (the energy efficiency gap, see Jaffe and Stavins, 1994a). Indeed, theoretical studies on credence goods such as Emons (1997) and Dulleck and Kerschbamer (2006) suggest that asymmetric information induces a reduction in trade volume on credence goods market. The necessity to trust expert-sellers comes from the possibility of inefficient supply-side behavior, which can be classified in three possible outcomes: (i) expert-sellers supply a lower quality than what the consumer needs (undertreatment), (ii) the quality supplied is higher than what is needed (overtreatment), and (iii) expert-sellers charge for good or services that are of higher quality than what is actually supplied (overpricing). While asymmetric information is only one of the factors affecting the energy efficiency gap, understanding how the market fails in relation to supply-side incentives is important for the design of public policies.[3]

[2] Energy transforming technologies may require an installation (e.g. solar panels or weatherization, hereafter installation goods) or can directly be used by consumers (e.g. a car or a fridge, hereafter appliances). As we discuss below, both the characteristics of the technology and the quality of the installation affect realized energy savings and can give rise to information asymmetry.

[3] Gerarden et al. (2017) distinguish between three categories of factors explaining an energy efficiency gap: market failures (including asymmetric information), deviations from the canonical behavioral framework (e.g. loss aversion), and flaws in the modeling framework such as incorrect cost calculations for some of the options. As we discuss in the text below, some behavioral and modeling flaws can be seen as originating from the credence component of energy technologies.

Dulleck and Kerschbamer (2006) suggests two institutional features of credence goods markets that can potentially restore market efficiency without external intervention. First, *verifiability* refers to a case in which consumers are able to verify the characteristics of the product after installation. Second, *liability* represents a case in which expert-sellers are liable to solve the consumers' problem. Under specific conditions, which we discuss in detail below, either verifiability or liability leads to efficient trade in the market for credence goods. In the context of energy efficiency investments, however, neither verifiability nor liability are likely to solve the informational problem. The key reason is the impossibility to ascertain, for each possible technology available on the market, actual energy savings that will be achieved. Also ex-post, after purchase and/or installation, measuring energy use per unit of service and defining a valid counterfactual remain a costly and challenging endeavor (see e.g. Joskow and Marron, 1992; Burlig et al., 2017). Realized energy savings are influenced by exogenous factors such as the weather and endogenous factors such as changes in the consumption of energy services. This leads us to discuss energy contracting as a way to align supply- and demand-side interests (see e.g. Sorrell, 2007; Klinke, 2018). But the difficulty to credibly quantify energy savings for many relevant energy-transforming technologies implies that contracting can only provide an idiosyncratic solution to the problem of asymmetric information.

In Section 3, we turn to a review of the empirical evidence from the credence goods literature, building on the work of Kerschbamer and Sutter (2017). This part of the paper overviews results from experimental markets for credence goods, as well as field evidence for products such as car repairs, taxi rides, and medical treatments.[4] This affords the second main contribution of our paper, namely drawing implications of the credence goods literature for the design of policies targeting the adoption of energy-efficient technologies. Our objective is to use the drivers of market inefficiencies identified in the credence goods literature to organize and discuss contributions to the energy efficiency literature. Doing so, our work provides a novel perspective on empirical evidence derived in the context of energy efficiency.

Concretely, we consider four important characteristics that affect supply-side behavior in markets for credence goods. First, we discuss the degree of informational asymmetry between

[4] In our view, experimental and field studies provide complementary evidence. The former allows to systematically varies selected institutional aspects of decisions in a controlled environment, while the latter quantifies the magnitude of inefficiencies for real-world decisions.

consumers and expert-sellers, and the conditions under which mitigating the information gap reduces market inefficiency. Experimental evidence by Balafoutas et al. (2013) suggests that consumers who signal to be informed about the characteristics of a credence good are more likely to receive a correct treatment. In the context of energy efficiency, informing consumers is directly related to the use of energy efficiency labels (see e.g. Newell and Siikamäki, 2014). Our reading of the literature leads us to emphasize the trust component in energy efficiency labels, and the role for independent third parties (or competing experts) to test whether the actual performance of labeled technologies corresponds to the declared energy efficiency. Moreover, in an effort to enforce trust on the market for energy efficiency, we highlight the need to make suppliers liable to deliver products that are in line with the labels.

The second dimension of credence goods markets we consider is the necessity to carry out a diagnostic, and the ensuing possibility to separate diagnostic from treatment. In the context of energy efficiency, this can take the form of independent energy audits. Supply-driven inefficiencies are expected to decrease if one expert is paid to perform the diagnostic and another expert is paid to perform the treatment, as the diagnosing expert has no incentives to recommend inappropriate products. The literature on credence goods, however, suggests that separate diagnostic can also worsen inefficiencies because it introduces an additional cost to market participation (Greiner et al., 2017; Mimra et al., 2016). We also discuss the possibility of ex-post auditing (Allcott and Greenstone, 2017) as another approach to improve market efficiency in a credence goods framework. Policies that lower the cost of third party audits, both before and after purchase/installation can mitigate the credence component of energy technologies and favor trust in the behavior of expert-sellers.

Third, we discuss how third party reimbursement reduces market efficiency in credence goods markets (e.g. Kerschbamer et al., 2016; Balafoutas et al., 2017). In particular, empirical evidence shows that experts are inclined to overtreat and overprice consumers whenever a third party (e.g. insurance or employer) covers the cost of the treatment. The use of subsidies for energy efficient technologies makes these results highly relevant for the design of energy and environmental policy. We relate results from credence goods markets to empirical evidence on the use of subsidies such as Pless and van Benthem (2017) and Allcott and Sweeney (2017). Overall, results suggest that the presence of asymmetric information diminishes the effectiveness of subsidies in the adoption of energy efficient technologies, although further research on how subsidies affect pricing behavior by expert-sellers is needed.

Finally, we examine the role of reputation and repeated interactions in the context of credence goods in general and energy efficiency in particular. The basic credence goods model suggests that honest expert-sellers will be driven out of the market, which is reminiscent of the lemon problem discussed in Akerlof (1970). Providing mechanisms for expert-sellers to signal their trustworthiness, such as neutral third parties publishing credible information about quality of service received, can contribute to help expert-sellers establish a good reputation. We emphasize, however, that the difficulty to quantify energy savings is again crucial for reputation-building by expert-sellers and whether consumers trust reputation information (see Gillingham and Tsvetanov, 2018).

The paper concludes in Section 4 by summarizing policy implications of our work and bringing together suggestions for future research.

2 Credence goods and energy efficiency

This section discusses the relationship between credence goods and energy efficiency. First, we briefly describe information asymmetries associated with credence goods and implied market inefficiencies using the general framework of Dulleck and Kerschbamer (2006) and the related experimental procedure by Dulleck et al. (2011). Second, we present a simple representation of decisions to invest in energy efficiency and clarify the sources of asymmetric information on the market for energy efficiency. Finally, we discuss verifiability and liability in the context of energy efficiency investments, as well as the role of energy contracting.

2.1 Credence goods and market inefficiencies

As in Dulleck and Kerschbamer (2006), consider a consumer with a problem that can be either minor or severe. The consumer, however, does not know which of the two conditions he faces, and hence whether an expensive treatment q_h or a cheap treatment q_l is needed. This classification mirrors a setting in medical treatments or car repairs, but it can also be interpreted more broadly as representing preferences of a consumer for a particular product or service. What sets credence goods apart from other goods is incomplete knowledge about own needs, both before and after treatment (Emons, 1997). To assess which good q_h or q_l is needed, the consumer relies on an expert-seller to perform a diagnostic. The expert-seller then recommends either q_h or q_l, supplies the good, and charges either p_h or p_l (with $p_h > p_l$). Note that, since the consumer does not observe his condition after treatment, either prices can be charged regardless of the good supplied.

This simple setting is the basis of the experimental market for credence goods studied in Dulleck et al. (2011) and implemented as a stage game in which one consumer interacts with one expert-seller. Throughout the game, each consumer only knows that q_h is needed with probability h and q_l with probability $1 - h$ (h is set to 0.5). The expert-seller faces a cost for performing high vs. low treatments, with $c_h > c_l$, and these costs are common knowledge. One implication is that, by observing prices, the consumer can determine markups and hence incentives for expert-sellers to supply either goods.

In the first stage, the expert-seller posts prices p_h and p_l, and the consumer decides whether he wants to participate in the market or not. If the consumer opts out, the stage game stops and both participants receive an outside option $o > 0$. If the consumer opts in, the game moves on to a second stage in which the expert-seller learns about the severity of the consumers problem (akin to a diagnostic), elects to supply either q_h or q_l, and charges either p_h or p_l (independently of the treatment performed). At the end of the stage game, the payoffs for expert-sellers is the difference between the price charged and the cost of the good supplied: $\pi_s = p_{charged} - c_{supplied}$. For the consumer, if the problem is solved ($q_{supplied} \geq q_{needed}$), the payoff is $\pi_c = v - p_{charged}$, where $v > 0$. If instead $q_{supplied} < q_{needed}$, $v = 0$ and the consumer gets $\pi_c = -p_{charged}$.

In this setting, market efficiency requires that the sum of surpluses is maximized. With the baseline parametrization, this occurs when the consumer opts into the market, and the expert-sellers recommends the appropriate treatment and charges the corresponding price. However, asymmetric information gives rise to three types of supply-side behavior that lowers trades and reduce market efficiency. First, *undertreatment* occurs if the consumer needs q_h, but the expert-seller supplies q_l. This implies that the problem of the consumer is not solved, hence $v = 0$. Second, *overtreatment* occurs when the consumer needs q_l but receives q_h. In this case the problem is solved ($v > 0$), but some of the tasks performed by the expert-seller were unnecessary. Third, *overpricing* is a situation in which the consumer receives q_l and is charged p_h, so that the consumer pays for a good that he did not receive.

A purely selfish expert-seller who maximizes own surplus always supplies q_l and charges p_h

(i.e. $\pi_s = p_h - c_l$). For consumers who need q_l this implies overpricing, while for those needing q_h both overpricing and undertreatment occur simultaneously. Experimental results by Dulleck et al. (2011) show that 88 percent of consumers in the q_l condition are subject to overpricing, and 53 percent of consumers in the q_h condition are undertreated. Moreover, as overtreatment is always dominated by overpricing ($p_h - c_l > p_h - c_h$), it is only observed in 6 percent of all interactions (although it is frequently observed in many real world markets for credence goods, see e.g. Rasch and Waibel, 2017; Baniamin and Jamil, 2018; Gottschalk et al., 2017).

Similar to the lemon problem in Akerlof (1970), profit maximizing experts who undertreat and overprice are expected to drive out of the market good experts who install adequate quality and charge adequate prices. Moreover, consumers who expect selfish behavior by expert-sellers are better off opting out of the market ($\pi_c = o$), leading to a collapse of the market. In Dulleck et al. (2011), the share of consumers who opt out increases from around 40 percent in the first period to about 80 percent in the last period. Furthermore, consumers who are undertreated in period $t-1$ are significantly less likely to opt out of the market in period t. While complete market breakdown does not occur, mainly because some expert-sellers display other-regarding preferences and do not undertreat (see also Kerschbamer et al., 2017), the low level of trades is associated with significant market inefficiencies.[5]

2.2 Energy efficiency as a credence good: A simple framework

We now present a simple model to discuss the credence nature of energy efficient technologies. We combine the representation of energy efficiency investment decisions by Allcott and Greenstone (2012) with the primitives of credence goods model by Dulleck and Kerschbamer (2006) discussed above. Specifically, we consider two different versions of an energy-transforming technology, namely an energy efficient version q_h and an energy inefficient version q_l. The upfront price for each option p_h and p_l covers the technology and its installation, and subsequently consumers pay the energy cost associated with the quantity of energy services consumed, denoted

[5] Beck et al. (2014) replicate this experimental design with car mechanics instead of the usual students subject pool, with comparable results. A key difference is that mechanics are found to be more likely to overtreat, although the difference declines as the game is repeated.

m_i.[6]

In this setting, consumers differ according to their consumption level $m_h > m_l$, which is assumed to determine the cost-minimizing technology: for a high usage type m_h, the more efficient version q_h is cost minimizing, whereas for low usage type m_l technology q_l is cost minimizing. Formally, q_h is cost-minimizing whenever the following inequality holds:

$$\frac{p_e \, m_i \, (e_l \,-\, e_h)}{1+r} \quad > \quad p_h \,-\, p_l \,, \tag{1}$$

where p_e is the private unit cost of energy, e_l and e_h represent energy intensity of each technology (with $e_l > e_h$), and $r > 0$ is a risk adjusted discount rate.[7] However, the consumer cannot know whether the inequality holds, and hence whether he needs q_h or q_l. First, energy efficiency as measured by e_l and e_h cannot be directly observed by consumers. Instead, they need to rely on external information in the form of engineering or sales agent expertise (unless there is some certification, something we discuss below). Second, the consumer typically only imperfectly observes m_i, and there is potentially some cost to ascertain it. By contrast, an expert-seller knows both e_l and e_h, and can perform a diagnostic to quantify m_i (e.g. by estimating energy consumption behavior or predicting it based on individual characteristics such as household size and habits). It follows that energy efficiency investments involve a component of faith in evidence provided by the supply-side of the market.

Our setup enables us to relate asymmetric information on energy savings ($m_i(e_l - e_h)$), which determine which technology is cost-minimizing, to supply side inefficiencies inherent to credence goods. While we discuss evidence on supply-side inefficiencies in details below, here we summarize the outcomes that are associated with lower trade volume and market efficiency in the credence good framework. First, undertreatment occurs when the energy efficient technology q_h is cost-minimizing, but the energy inefficient technology q_l is supplied. Intuitively, for high usage m_h consumers, savings on energy expenditures associated with the energy efficient

[6] The framework can easily accommodate a situation where the inefficient option is the status quo, as in Allcott and Greenstone (2012), by setting $p_l = 0$. Considering instead a replacement decision is closer to the setting of Dulleck et al. (2011) in which the consumer faces a problem and seeks a treatment.

[7] The parameter m_i is assumed to be unaffected by the type of technology installed. This abstracts from a rebound effect and is in line with Allcott and Greenstone (2012).

technology more than compensate higher investment costs.[8] Second, overtreatment implies that q_l is cost-minimizing for the consumer (i.e. the consume is of type m_l), but the expert-seller supplies q_h. Third, overpricing corresponds to a case in which the energy inefficient technology q_l is installed but the price of the energy efficient technology q_h is charged. These outcomes emphasize the trust component inherent in energy efficiency investment, and may exacerbate perceived risks associated with energy efficient technologies (Gillingham and Palmer, 2014). In turn, this may lead consumers to stay out of the market, thereby contributing to the energy efficiency gap.

2.3 Verifiability, liability, and energy contracting

Dulleck and Kerschbamer (2006) highlights two features of credence good markets that can restore market efficiency without external intervention, namely verifiability and liability. In the following, we discuss each institutional feature in the context of energy efficient technologies. This leads us to discuss how energy contracting provides a potential solution to inefficiencies associated with credence nature of energy efficiency.

2.3.1 Verifiability and energy efficiency

Under verifiability, consumers are able to identify, after treatment, whether the expert-seller has installed q_h or q_l. As a consequence, verifiability rules out the possibility of overpricing, and the expert will supply the treatment that maximizes his profits. In the context of Dulleck and Kerschbamer (2006), where consumers know c_i, expert-sellers can only attract consumers under equal markups: $p_h - c_h = p_l - c_l$.[9] Together with an assumption that expert-sellers install the appropriate quality whenever they are indifferent, this leads to an efficient outcome (see Emons, 1997, for a similar result).

Experimental results from Dulleck et al. (2011) indicate, however, that verifiability does not increase market efficiency compared to the baseline. There are two main reasons for this. First,

[8] In our setup, it does not matter whether the appropriate quality is recommended by the expert and then inappropriately installed or whether inappropriate quality is recommended in the first place. In both cases, the consumer ends up being undertreated.

[9] If the markup associated with one of the treatments is higher, the associated product can be expected to be supplied independently of the actual condition faced by the consumer. In the experiment by Dulleck et al. (2011), this implies that the probability of overtreatment and undertreatment is one half.

equal markup prices are posted in only four percent of interactions, which gives rise to incentives to overtreat or undertreat. Second, some expert-sellers display antisocial preferences, leading them to supply the inappropriate treatment even if it generates lower profits (see Kerschbamer et al., 2017, for further evidence on this). The impact of verifiability on market efficiency in experimental credence goods markets is therefore limited.

In the context of energy efficiency, verifiability requires that consumers are able to observe the technology purchased and quantify its energy intensity (e_i) after installation. In other words, both the technology and the quality of its installation have to be verifiable by the consumers. One implication is that energy technologies are prone to a difference between ex-ante values for e_i, which may be used by expert-sellers to market their products, and realized values for e_i measured in the field. For example, Davis et al. (2014) studies a program to replace inefficient refrigerators in Mexico, finding that realized savings are only one quarter of predicted savings. While it is difficult to generalize findings from a particular program, evidence from an early meta-analysis by Nadel and Keating (1991) confirms a systematic upward bias in ex-ante predictions.

A related challenge to verifiability is that measuring energy savings requires a valid counterfactual of energy consumption (e.g. with an inefficient technology, see Joskow and Marron, 1992). In fact a branch of the literature on energy efficiency is dedicated to the estimation of energy savings in buildings. For example, Dubin et al. (1986) and Fowlie et al. (2018) use randomization in the field to estimate counterfactual energy consumption, while Burlig et al. (2017) employs machine learning techniques to product energy use in the absence of energy retrofits. These studies also confirm that realized energy savings tend to be systematically below ex-ante estimates. This suggests that the difficulty to identify the quality of installation incentivizes expert-sellers to overstate the quality of their product, as measured by e_i, a form of undertreatment.

In sum, the difficulty for consumers to measure e_i both before and after purchase imply that verifiability is unlikely to improve market efficiency. In turn, supply-side incentives are likely to induce some consumers to stay out of the market, reducing participation on the market for energy efficiency. Policies targeting energy efficiency therefore need to consider the role of trust between the supply and demand sides of the market.

2.3.2 Liability and contracting for energy efficiency

Under liability the expert is made liable for supplying an appropriate treatment. In the setup of Dulleck and Kerschbamer (2006) and Dulleck et al. (2011) a liable expert does not have the possibility to install q_l if the consumer needs q_h, ruling out undertreatment. Reducing the expected loss for consumers nearly doubles the number of trades. However, market efficiency is hampered by overpricing, which is still observed in 75 percent of the cases (recall that overtreatment is always dominated by overpricing).

While liability can easily be introduced in a laboratory environment, in the field undertreatment may not systematically be detected. In the case of energy efficiency, quality control is difficult to enforce (Gerarden et al., 2017), incentivizing expert-sellers to cut down costs at the installation stage and undertreat consumers. For example, field evidence by Giraudet et al. (2018) suggests that quality of retrofit (attic insulation and duct sealing) as measured by energy savings is lower when installed on a Friday, which is interpreted as a way to cut down labor costs before the weekend. Moreover, even if undertreatment is detected, for example in the form of sloppy installation, a consumer cannot press charges, as energy consumption (and associated realized energy savings) may fluctuate for reasons other than supply-side behavior.

One approach to enforce liability and mitigate undertreatment is energy contracting , which sets incentives for expert-sellers to install the cost minimizing technology (Tietenberg, 2009). In particular, under an energy performance contract, the expert-seller selects and installs the technology, and is subsequently entitled to a share of the realized energy savings and associated financial gains. The structure of the contract should be such that expert-sellers maximize profits by installing the cost minimizing technology. Energy performance contracts would therefore make undertreatment unattractive, as expert-sellers would forgo profits from increased energy savings. Similarly, overpricing is prevented since the expert-sellers bears the installation costs. The contract may also specify further incentives for the expert-seller to maintain or improve the performance of the equipment over time (see Sorrell, 2007).

The fact that energy contracting can mitigate supply-side inefficiencies highlights an important specificity of energy efficient technologies: financial savings associated with the cost-minimizing option are spread into the future. In practice, however, getting consumers and expert-sellers to contract on energy technology faces a number of barriers. First, the difficulty to define a baseline to determine energy savings remains, and has given rise to an International Verification and Measurement Protocol in which standardizes the estimation of energy savings based on a before/after comparison and ad hoc adjustments in the consumption of energy services (see Efficiency Valuation Organization, 2018). Second, Klinke (2018) provides survey evidence that economic viability is a significant barrier, mainly because of the risk associated with future energy savings. For example, external factors such as the weather may affect realized energy savings and induce a risk that the supply-side may not be willing to hold.

We conclude that the costliness to predict and measure energy savings associated with energy efficiency investments, and the difficulty to make expert-sellers liable for failures to deliver energy savings in line with ex-ante projections, is a key hurdle for liability in general and for energy contracting to play a significant role in the adoption of energy efficient technologies.

3 Empirical evidence from credence goods markets: Implications for energy efficiency policies

In this section we review existing empirical evidence on credence goods markets and draw links to the literature on energy efficiency. Our main objective is to identify policy implications of supply-side incentives associated with the credence component of energy technologies. The structure of our argument broadly follows Kerschbamer and Sutter (2017), and we focus on four institutional features that are relevant for energy efficiency: (i) the degree of informational asymmetries and the role of certification; (ii) separation between diagnostic and treatment in relation to energy audits; (iii) third party reimbursement and subsidies to energy efficient technologies; and (iv) reputation and repeated interactions in a market for emerging technologies.

3.1 Informing consumers and certification

Market inefficiencies associated with credence goods stem from an informational advantage held by the supply-side of the market. Therefore, a natural approach to improve market efficiency is to inform consumers. Indeed, as initially put forward by Darby and Karni (1973), market inefficiencies are proportional to differences in information. Imperfect information on the market for energy efficient technologies has been identified as an important driver of market inefficiencies (e.g. Allcott and Wozny, 2014; Jacobsen, 2015). For consumers, information on e_l, e_h and m_i

(from energy labels or any other sources) would transform energy efficiency in a search good, thus reducing a key source of market inefficiencies (expert diagnostic as a source of information is discussed in the next section).

Field experimental evidence in the context of taxi rides reported by Balafoutas et al. (2013) quantifies how the supply-side of the market exploits the degree of asymmetric information. The authors find that taxi drivers (expert-sellers of cab rides) are more likely to overtreat consumers who explicitly state that they are unfamiliar with the city by taking them on a detour. Moreover, when a consumer signals to be a foreigner, the probability of that the driver applies a false tariff and charges extra fees increases, and these are both instances of overpricing. By contrast, consumers who signal some degree of expertise about the product considered (e.g. by using a navigation service to suggest directions to the driver) are subject to significantly less overtreatment and overpricing. Similarly in the medical domain, Gruber et al. (1999) and GruberOwings1996 study the frequency of natural births and cesarean deliveries as a function of the physicians' incentives. They report evidence that the probability of cesarean delivery is different if women have a physician in their family, which presumably reflects lower informational asymmetry.

In the context of energy efficiency, labels for energy-using appliances are now widespread (e.g. for the U.S. U.S. Federal Trade Commission, 1979; European Commission, 2013, and the EU respectively). For example, Newell and Siikamäki (2014) test alternative designs for information contained in energy labels, suggesting that information on financial savings is critical in helping consumers select the cost-effective option. A closely related research endeavor is Davis and Metcalf (2016), which shows that providing tailored information on usage rates results in more cost efficient choices. This is in line with equation (1) in which asymetric information is driven by the terms m_i, e_l, and e_h.

However, given the credence nature of energy efficiency, trustworthiness of labels is a central issue. Goeschl (2018) finds systematic discrepancies between self declared and verified energy efficiency ratings of refrigerators sold in the EU market. Certification thus requires independent third parties to credibly verify claims about energy efficiency of technology made by their producers. Recent manipulation of fuel consumption and emissions information in the car making industry (e.g. U.S. Environmental Protection Agency, 2018) suggests that making producers liable for undertreatment is also important. In particular, given supply-side incentives associated with the market for energy efficiency, labels are not sufficient to make the information available to consumers trustworthy and choice-relevant. This, in turn, could at least partly explain why consumers remain inattentive to this information (Sallee, 2014; Allcott and Knittel, 2017).

One potential avenue to address the trust problem underlying certification is competitor testing. Competing expert-sellers have an incentive to verify whether the product of competitors meet the standards and report inconsistencies to a regulator. In concentrated markets, Plambeck and Taylor (2019) show that competitor testing can be more effective than testing by a regulator when violations of the standard lead to fines or restricted market access. The authors also show, however, that entry of non-compliant firms with low-quality products is possible when the market share of these low quality products is small and not sufficient to draw competitors to test the products. It follows that certification and testing by a regulator remains relevant. But in both cases, incentives for violation of product standards need to be recognized and addressed in order for consumers to trust information conveyed by certification.

Another implication of the credence nature of energy efficiency is that certification may induce expert-sellers to increase markups associated with energy efficient products. When costs are unobserved, consumers are unable to determine whether higher prices reflect higher cost or surplus appropriation by the expert-seller. Houde (2018) studies pricing behavior for suppliers of refrigerators who have have lost their energy certification, and estimates that certification increases the price of products by 2 to 5 percent. This suggests that certification on markets for credence goods can lead to price distortions, leading expert-sellers to partially appropriate expected benefits associated with lower energy consumption. In turn, higher prices can be expected to reduce the demand for energy efficient technologies.[10]

Finally, while certifications usually focuses on e_l and e_h, information may also come in the form of general recommendations, which may reduce the degree of asymmetric information when a diagnostic is performed. For example, the U.S. Department of Energy provides web-based guidelines on how consumers can perform energy audits themselves or estimate their

[10] A related paper by Fisher (2010) shows that vehicle manufacturers strategically select fuel efficiency of vehicles to extract surplus from consumers with alternative tastes for this characteristic of vehicles.

energy use for certain services.[11] This source of information can supplement the diagnostic of an expert-seller and can be used to signal knowledge about personal needs. However, we note that Gottschalk et al. (2017) reports field evidence in the context of dental care that such information does not necessarily increases market efficiency. In particular, the authors find that patients who signal knowledge obtained from an internet dentist platform, which provides information on diagnostics, do not benefit from a lower probability of overtreatment.

3.2 Separating diagnostic from treatment and independent energy audits

Energy audits provide information on the appropriate (cost-minimizing) treatment for consumers. However, if it is performed by an expert who also supplies the treatment to the consumer, supply-side incentives suggests that it may lead to a problem of supply-induced demand (e.g. for whichever option affords higher markups). This issue can be addressed by separating the diagnostic from the treatment, so that the expert performs the diagnostic while a seller supplies a treatment. While this reduces the scope to exploit asymmetric information, the consumer may have to pay for a diagnostic separately. This creates an additional barrier to the provision of a credence good.

Greiner et al. (2017) studies the separation of diagnostic and treatment experimentally in the context of a physician-patient relationship. When the diagnostic is free, consumers are more likely to seek one and treatment take-up increases. However, even though the seller is forced to stick to the diagnostic provided by the expert, overtreatment still occurs in 20 percent of all transactions (51 percent in the baseline), and undertreatment increases from 7 to 24 percent.[12] These results presumably reflect spiteful behavior by auditors since they earn no diagnosis fee. However, when the diagnostic is costly, fewer patients seek a diagnostic and market efficiency declines. These effects are confirmed in a related experiment by Mimra et al. (2016), which shows that the possibility for consumers to obtain multiple diagnostics before they interact with an expert-seller lowers the probability of overtreatment, whereas diagnostic fees again reduce

[11] See for example the Energy Saver Program of the U.S. Department of Energy (2018). By contrast, the National Energy Audit Tool (U.S. Department of Energy, 2012) is designed for experts on the supply side (utility companies, residential energy professionals, auditors, energy consultants and analysts), rather than for untaught consumers.

[12] Note that the consumer can opt out of the market after a diagnostic, and the parameters of the experiment implies that both consumers and sellers benefit more from solving the high condition, so that overtreatment is expected. By contrast, in Dulleck et al. (2011) equal markups implies that overpricing dominates overtreatment.

overall welfare.

In the context of energy efficiency investments, Anderson and Newell (2004) discusses the role of energy audits and emphasizes the distinction between the independent auditor providing a diagnostic and the contractor who provides the service. Fleiter et al. (2012) study subsidized energy audits by independent contractors for small and medium companies. Survey evidence suggests that "consultants neutrality" was an important component of the program, which again highlights the importance of trust in this market generally and in the measures recommended by the expert in particular. However, empirical evidence reported in Fowlie et al. (2015) and Fowlie et al. (2018) suggests that the demand for energy audits by households is small, with few households signing up for highly subsidized energy audits. In turn, such strategies have limited effect on energy use (see also Abrahamse et al., 2005).

A related intervention is that of ex-post auditing, discussed in the field study by Allcott and Greenstone (2017). In a first step, an independent state-certified auditor performs a free diagnostic to assess the consumer situation (m_i) and recommends the level of energy efficiency. In a second step, a certified contractor installs the technology (insulation, heating, cooling). After the work is completed the independent contractor returns to verify that the technology has been installed adequately. Allcott and Greenstone (2017) finds that the sequence of audits increases the willingness to pay for unobserved (non-monetary) benefits associated with energy efficiency, leading 20 to 50 percent of consumers to install a technology with negative financial returns. A combination of ex-ante and ex-post auditing may therefore act as a safeguard to supply side inefficiencies arising from credence component of energy technology, although the cost of these audits may significantly increase the barrier to energy efficient technology adoption.

3.3 Third party reimbursement, subsidies and markups

Third party reimbursement represents a situation in which an expert-seller knows that the price charged will (at least partly) be borne by a third party. In the credence goods literature, this is typically an insurance. Both theoretical predictions and empirical evidence shows that this leads expert-sellers to overtreat and overprice consumers, and increase market inefficiencies. We argue that this line of research is relevant for the design of energy efficiency policy, in which subsidies often play an important role. In particular, subsidizing credence goods is likely to affect pricing behavior or induce subsidy manipulation, and in turn the incentives of an expert-seller to provide adequate services provision.

Kerschbamer et al. (2016) provides field evidence on third party reimbursement in the market for computer repairs. When an expert-seller knows that the consumers is insured, the average bill for a pre-specified problem is EUR 129, as compared to EUR 59 when the consumer bares the full cost of the reparation. About one third of the difference is due overtreatment (performing unnecessary repairs), the rest being explained by overpricing (charging for services which were not provided). Similar results for taxi rides are reported in Balafoutas et al. (2017), as passengers who state that their expenses are reimbursed are more likely to be taken on a detour. In the healthcare context, field evidence shows that physicians are more likely to overtreat when patients are insured (Iizuka, 2007, 2012; Lu, 2014), and Huck et al. (2016) replicate this finding in a laboratory experiment. [13]

In our framework, subsidizing the energy efficient technology reduces p_h, which makes it more likely that q_h is cost-effective for a given m_i. Therefore the traditional view is that subsidizing energy efficient technologies accelerates their adoption (Jaffe and Stavins, 1994b; Comstock and Boedecker, 2011). However, results from the credence goods literature also indicate that expert-sellers are prone to manipulate both diagnostic and delivery to appropriate (part of) the subsidy. While empirical evidence on this issue is scarce, Pless and van Benthem (2017) exploit data from solar panel installations showing that increasing subsidies by one dollar reduces the price for solar systems by 86 cents. However, because subsidies are based on the components that are installed, and given the difficult to verify the installation component, both overpricing and overtreatment are likely to occur in this setting.

Subsidies may therefore affect supply-side incentives, notably through markups. In turn, existing evidence suggests that expert-sellers will supply alternatives that generate the higher markups. Iizuka (2007) shows that physicians who can directly sell drugs to patients are more likely to prescribe those that affords higher markups. In the context of energy efficiency, Allcott and Sweeney (2017) provides experimentally controlled evidence on the behavior of sales agents in a call center offering water heaters to potential consumers. In this context, the authors find a strong complementarity between financial incentives for the seller and those for

[13] In addition to supply-side moral hazard, the authors also find evidence of demand side moral hazard, as insured patients tend to consult physicians more often.

consumers.[14] In particular, such joint incentives affect both the probability that the seller mentions financial savings associated with the energy efficient water heater and the number of sales of the more energy efficient appliances. By contrast, a consumer rebate without sales incentives does not lead the seller to disclose information about financial savings associated with the energy efficient appliance, strategically marketing the energy efficient version to a small minority of responsive consumers.

In sum, subsidies for energy efficiency interact with supply-side incentives, and given the lack of verifiability and liability on the market for energy efficiency this may favor strategic information disclosure. In turn, further research should be directed at the design of subsidies in a market for credence goods and their impacts on prices.

3.4 Reputation and repeated interactions

In a context where trust matters, expectations about repeated interactions between expert-sellers and consumers may encourage honest behavior. In line with this, Dulleck et al. (2011) finds that providing consumers with information about interactions in previous-rounds reduces overpricing, and increases the number of trades. Reputational concerns can potentially be relevant in the market for energy efficiency, for example by providing trustworthy information about past behavior.[15]

Field evidence from car repairs by Rasch and Waibel (2017) suggests that garages in vicinity of a highway, and who are presumably less orientated towards repeated business, overprice more frequently. Similarly, Schneider (2012) finds that diagnosis fee for car repairs is significantly higher if consumer signals a one-shot interaction (stating to be moving away after the service and having moving boxes in the trunk). Note, however, that Schneider (2012) finds no evidence that signaling repeated business opportunities affect the quality of service, as undertreatment occurs with similar frequencies for consumers who signal single or multiple interactions.

In the context of energy efficiency, repeated interactions is rare, which means that consumers cannot directly leverage reputational concerns to induce honest behavior. Nevertheless, the lit-

[14] Importantly, sales agents cannot appropriate the subsidy by manipulating prices, so that the markup is entirely driven by additional sales incentives.

[15] One example where bilateral feedback systems have successfully enforced trust are online markets for search goods (Tadelis, 2016).

erature studies several possible approaches to encouraging reputation building by expert-sellers in the market for energy efficiency. For example, Kraft-Todd et al. (2018) studies reputation building through words-of-mouth recommendations for the installation of solar panels. They show that communities in which an "ambassador" selected to promote solar installations himself installed solar panels through the program increases the share of resident who subsequently install a solar system.

One exception is the car market, where consumer can learn about unobserved quality attributes of hybrid vehicles through the experience of other consumers. Evidence reported in Heutel and Muehlegger (2015) suggest that higher penetration of the Toyota Prius has increases the market share of all other hybrids, while the Honda Insight reduces it. The authors interpret this finding as evidence that the former model is of higher quality, which can be associated with trust. By contrast, the latter model is deemed of lower quality, reducing overall trust for the technology across all other model.

In the absence of verifiability, however, ex-post quality assessment for households is costly (e.g. by an independent auditor), which implies that bilateral feedback schemes are likely to be driven by subjective assessments and herding effects. Instead, what is needed is a credible measures of the quality of expert-sellers, such as monetary and energy savings realized after the installation of energy efficient technologies.[16] In line with this, Gillingham and Tsvetanov (2018) studies a program in which households interested in performing an energy audit of their dwelling are provided with information on realized monetary and energy savings measured for other audited households. This provides credible information about the trustworthiness of the expert-seller. In turn, households who have access to such information are more likely to carry out an audit themselves.

4 Conclusion

In this paper, we have investigated the credence component of energy efficient technologies, arguing that the credence goods framework can be useful to further our understanding of the adoption of energy efficient technologies and the associated energy efficiency gap. The main

[16] As discussed above, competitor testing coupled with certification of experts is a potential solution, although it does not rule out supply side inefficiencies.

contribution of our work is twofold. First, based on a simple model of energy efficiency investments, we identify how asymmetric information can lead to three types of supply side inefficiencies discussed in the credence goods literature and reduced trade volume. Second, we survey an extensive empirical literature on credence goods and relate key empirical findings to the literature on the adoption of energy efficient technologies. We highlight the difficulty to provide ex-ante evidence on energy savings, the associated failure of both verifiability and liability, and the often observed discrepancy between ex-ante and ex-post energy savings. Taken together, this suggests that insights about inefficiencies inherent to credence goods, such as the baseline experiment of Dulleck et al. (2011), are useful to inform the market for energy efficiency.

Based on our review of the literature, we can summarize the implications of our work for energy efficiency policies as follows. First, while informing consumers is important, a lack of verifiability of energy savings can induce supply-side incentives to manipulate information. Therefore, certification schemes and labels involve a trust component, which implies that third party verification of information credibility is necessary, and requires some form of supply-side liability for the level of efficiency delivered. Second, in the presence of credence goods, access to independent diagnostic services helps consumers receive appropriate evaluations of their problem, and can be used to mitigate supply-induced inefficiencies. However, empirical evidence suggests substantial transaction costs associated energy audits. It follows that policies facilitating independent *ex-post* audits provide an alternative approach to mitigate supply-induced inefficiencies. Third, the credence component of energy efficiency also has implications for the design of subsidies. Expert-sellers may partly capture these through pricing behavior, including overpricing, and overtreatment may raise the cost of replacing existing technologies, and in turn reduce the demand. Understanding pricing behavior is therefore an important component in the design of subsidies.

Based on our discussion on the credence component of energy efficiency, we close with two relevant domains for further research. First, "contracting" supply side inefficiencies may theoretically solve the problems arising from asymmetric information on energy efficiency. While there exists some studies of contracting in the domain of energy efficiency, studying the role of contracting in the context of credence goods is an important research endeavor. Second, while research on energy labels is large and growing, evidence on the role of the trustworthiness of these labels is sparse. Given the importance of the credence component for energy technology, understanding the role of trust in energy certification also constitutes an important area for future research.

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