Asymmetric Information on the Market for Energy Efficiency: Insights from the Credence Goods Literature

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ABSTRACT

Asymmetric information is an important barrier to the adoption of energy efficient technologies. In this paper, we study supply-side implications of the associated incentive structure. We build on existing evidence that, in some settings, 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 an information advantage by expert-sellers 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 implications for the design of policies promoting the adoption of energy-efficient technologies.

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

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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-transforming technologies, consumers can potentially lower energy use without affecting the amount of services 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 en-

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).

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ergy technologies. The existing literature emphasizes informational failures that affect investment behavior, including imperfect information about and inattention to future energy savings (see also Gerarden et al., 2017).

We argue that, for a number of relevant energy-transforming technologies, the supply-side of the market may hold relevant information and have little incentives to share it with consumers. Based on this observation, this paper focuses on supply-side incentives associated with asymmetric information on the market for energy technologies and implied market inefficiencies.[2] As initially put forward by Sorrell (2004) and recently discussed by Giraudet (2020) and Plambeck and Taylor (2019), the type of informational asymmetry characterizing these energy-transforming technologies can be conceptualized under the notion of "credence goods," a class of goods for which consumers have incomplete knowledge about own needs both before and after purchase (Emons, 1997). For these goods, consumers have to trust information by an expert-seller who can perform a diagnostic and supply a particular product. In the case of energy-transforming technologies, consumers typically do not directly observe the level of energy efficiency of alternative technologies, and may not be able to ascertain which technology is cost-minimizing, both before and after purchase/installation.[3] In turn, when the supply-side of the market possesses an informational advantage, decisions to invest in energy-transforming technologies inherit the properties and inefficiencies identified in markets for credence goods.

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 goods 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 delivers the main contribution of this work, namely identifying how and when 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 to invest "too little" in energy efficiency, seemly failing to realize financial benefits from energy savings 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 markets. The necessity to trust expert-sellers comes from the possibility of inefficient supply-side behavior, which can be classified under 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 goods 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

2. Energy-transforming technologies may require an installation (e.g. heating systems) or can directly be used by consumers (e.g. technologies such as a fridge or a car). As we discuss below, the quality of both the technology and of the installation affect realized energy savings and can give rise to a component of trust in information provided by the supply-side of the market.

3. Many energy-transforming technologies are subject to governmental labeling regulations, which inform consumers about energy efficiency and mitigate information asymmetry. However, using this information to determine a cost-minimizing option can remain challenging for some consumers (e.g. Brounen et al., 2013). Moreover, as we discuss extensively below, a lack of ex-post verifiability implies supply-side incentives to manipulate information provided to consumers, even in the presence of labels (Houde, 2018; Goeschl, 2019).

efficiency gap, and may not affect all consumers and technologies equally, understanding how the market fails in relation to supply-side incentives is important for the design of public policies.[4]

Dulleck and Kerschbamer (2006) suggest 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 purchase/installation. Second, *liability* represents a case in which expert-sellers are liable to solve the consumers' problem. Under specific conditions, which we discuss below, either verifiability or liability leads to efficient trade in markets for credence goods. For many energy efficiency investments, however, neither verifiability nor liability are likely to solve the information problem. The key reason is the difficulty (or costliness) for consumers 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 challenging endeavor (see e.g. Joskow and Marron, 1992; Burlig et al., 2020). Realized energy savings are influenced by exogenous factors (e.g. the weather) and endogenous factors (e.g. changes in the demand for energy services). This leads us to discuss energy performance contracting as a way to align supply- and demand-side interests (see e.g. Sorrell, 2007; Klinke, 2018). However, insights from the credence goods literature suggest that the difficulty to credibly quantify energy savings for many relevant energy-transforming technologies limits the range of application of performance contracting.

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.[5] Our objective is to use the drivers of market inefficiencies identified in the credence goods literature to organize and discuss selected contributions to the energy efficiency literature. This affords the second main contribution of our paper, which is to provide a rejoinder of two separate but related streams of the economics literature, and thereby offer a novel perspective on supply-side incentives underlying investment decisions in energy-transforming technologies.[6]

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 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 and certification (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

4. 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.

5. In our view, laboratory experiments and field studies provide complementary evidence. The former allows to systematically vary selected institutional aspects of decisions in a controlled environment, while the latter quantifies the magnitude of inefficiencies for real-world decisions.

6. We note that empirical evidence derived from other credence goods markets may not apply directly in the context of energy efficiency investments. We argue, however, that many credence goods markets display patterns that are consistent with predictions from the model by Dulleck and Kerschbamer (2006), and that includes observations resulting from the energy efficiency literature. Linking empirical results from different domains is therefore important.

for independent third parties (or competing experts) to test whether the actual energy intensity of technologies corresponds to the certified 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 certification.

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 further 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. an insurance) 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 consumer subsidies and sales incentives studied by Allcott and Sweeney (2017). Overall, this suggests 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 lemons 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 some suggestions for further 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 that may affect specific technologies and consumers 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 performance 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.[7] 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 $p_h \geq p_l$). Note that, since the consumer does not observe his condition after treatment, either price 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 good.

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 problem faced by the consumer (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 supplied). At the end of the stage game, the payoff for expert-sellers is the difference between the price charged and the cost of the good supplied: $\pi_s = p_{\text{charged}} - c_{\text{supplied}}$. For the consumer, if the problem is solved ($q_{\text{supplied}} \geq q_{\text{needed}}$), the payoff is $\pi_c = v - p_{\text{charged}}$, where $v > 0$. If instead $q_{\text{supplied}} < q_{\text{needed}}$, $v = 0$ and the consumer gets $\pi_c = -p_{\text{charged}}$.

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. However, asymmetric information gives rise to three types of supply-side behavior that lower trade 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 are 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 quality 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 it implies undertreatment. 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

7. As discussed in Dulleck and Kerschbamer (2006), the framework can be adapted to a situation in which consumers' type is drawn from a continuous distribution, and they face multiple differentiated products. For the present discussion, however, a binary case is sufficient to identify the nature of the credence goods problem, and is also in line with the model by Allcott and Greenstone (2012) discussed below.

are undertreated. By contrast, overtreatment is only observed in 6 percent of all interactions, as it is always dominated by overpricing ($p_h - c_l > p_h - c_h$).[8]

Similar to the lemons problem in Akerlof (1970), profit maximizing expert-sellers who undertreat and overprice drive out of the market those 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 ($\pi_c = o$), which in equilibrium leads to market collapse. 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 more 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.[9]

2.2 Energy efficiency as a credence good: A simple framework

We now turn to energy-transforming technologies, which include heating and/or cooling systems, vehicles, lighting equipments, and electric appliances such as fridges or freezers. For all these products, alternatives available on the market are typically differentiated with respect to their energy efficiency (among other things). In the following, we discuss the credence nature of energy efficient technologies in the context of a simple model, combining 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.

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 m_i.[10] As per Dulleck et al. (2011), consumers can be of either one of two types, a high usage type m_h and a low usage type m_l, with $m_h > m_l$. The type of consumers in turn determines the cost-minimizing technology: for m_h the more efficient version q_h is cost minimizing, whereas for m_l technology q_l is cost minimizing.

Formally, q_h is cost-minimizing for consumer i whenever the following inequality holds:

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

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.[11] We argue that, in many instances, the consumer cannot know whether the inequality holds, and hence whether he needs q_h or q_l. First, energy

8. This is a results of the parametrization of the experiment. In real world markets for credence goods, overtreatment is frequently observed (see e.g. Rasch and Waibel, 2017; Baniamin and Jamil, 2018; Gottschalk et al., 2020). Note also that the results from this experimental procedure were successfully replicated by Camerer et al. (2016).

9. Beck et al. (2014) replicate this experimental design with car mechanics instead of a 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.

10. The framework can easily accommodate a situation in which 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 solution.

11. For simplicity, usage-rate 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).

efficiency as measured by e_l and e_h cannot be directly observed by consumers. Instead, consumers 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, while some consumers may be relatively well informed about their usage rate m_i, it is typically imperfectly observed, and there is potentially some cost to discover it. Consumers may also lack the expertise to translate information about m_i into energy use (e.g. in kWh), be unaware of energy prices p_e, or may have difficulties to perform present-value comparisons. By contrast, an expert-seller can ascertain both e_l and e_h, and determine the type of consumers m_i for whom inequality (1) holds.

A crucial component of this framework are energy savings ($p_e m_i(e_l - e_h)$), which determine the cost-minimizing technology, and asymmetric information on its constituting elements can give rise to market inefficiencies and low trade volume inherent to credence goods (Sorrell, 2004; Giraudet, 2020). In particular, while we discuss evidence on supply-side inefficiencies in detail below, possible outcomes identified in the credence goods literature can be summarized as follows. First, undertreatment occurs when q_h is cost-minimizing (i.e. the consumer is of type m_h), but instead q_l is provided (independently from the price charged).[12] Second, overtreatment implies that q_l is cost-minimizing for the consumer (i.e. the consumer is of type m_l), but the expert-seller delivers q_h (independently from the price charged). Third, overpricing corresponds to a case in which q_l is installed but the price of q_h is charged.

Importantly, in practice there is heterogeneity across both consumers and energy technologies. For example, a consumer on the market for cars may know average distance driven per year (m_i), the price of gas (p_e), comprehend fuel-efficiency information provided by car manufacturers (e_l and e_h), and be able to identify a cost minimizing alternative. Empirical evidence for the general population, however, suggests that energy literacy is relatively low. For example, using a survey of Dutch households, Brounen et al. (2013) reports that only 56% know their energy expenditures and 40% were not able to make a comparison between long-term savings and upfront investment cost (akin to equation 1; see also Jessoe and Rapson, 2014 and Blasch et al., 2019 for further evidence on energy literacy). Moreover, supply-side profit maximization motives imply incentives to manipulate information, which may lead to fraudulent behavior even in the presence of sophisticated reporting standards such as those applied in the U.S. car industry (see U.S. Environmental Protection Agency, 2018). For other energy efficiency investments, such as thermal insulation, supply-side (e.g. architects) informational advantage seems even more acute.

Ideally, consumers on the market for energy-transforming technologies would perfectly observe realized energy savings for all technologies, and based on this determine which technology is best suited for their needs. When this cannot be observed, investment decisions involve a component of trust (independently from perceived risks, see Gillingham and Palmer, 2014). In turn, this may lead some consumers to stay out of the market, thereby contributing to the energy efficiency gap. Based on this, we proceed with a discussion of how properties of credence goods markets contribute to the extent of market inefficiencies, and relate these to energy efficiency investment decisions and policies affecting these.

2.3 Verifiability, liability, and energy contracting

Dulleck and Kerschbamer (2006) highlight two features of credence good markets that can restore market efficiency without external intervention, namely verifiability and liability. In the

12. Intuitively, for high usage m_h consumers, savings on energy expenditures associated with the energy efficiency level e_h more than compensate higher investment costs p_h.

following, we discuss both institutional features in the context of energy efficient technologies. This leads us to consider energy performance contracting as a response to the credence component of energy efficiency investments.

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_h and c_l, expert-sellers can only attract consumers under equal markups: $p_h-c_h=p_l-c_l$.[13] Together with an assumption that expert-sellers install the appropriate quality whenever they are indifferent, this leads to the 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, 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 whether technology q_h or q_l is operating, which implies measuring (verifying) realized energy savings $\hat{m}_i(\hat{e}_l-\hat{e}_h)$ after purchase/installation. For a number of energy-transforming technologies, it may be possible to monitor energy use (e.g. by measuring it with a smart meter), although this requires time and effort. Moreover, one empirical challenge to verifiability is the definition of a valid counterfactual for 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 achieved by improving energy efficiency in buildings. For example, Dubin et al. (1986) and Fowlie et al. (2018) use randomized controlled trials to estimate counterfactual energy consumption of renovated buildings, while Burlig et al. (2020) employ machine learning techniques to predict energy use in the absence of energy retrofits. However, for individual investors the difficulty to quantify realized energy savings remains.

An absence of verifiability creates incentives for the supply-side of the market to manipulate information about expected energy savings. Therefore, the framework suggests that investments in energy efficient technologies are prone to a systematic bias of ex-ante projections for energy savings $m_i(e_l-e_h)$ relative to realized energy savings measured after purchase/installation $\hat{m}_i(\hat{e}_l-\hat{e}_h)$. This is in line with early empirical evidence from Nadel and Keating (1991), which reports that engineering estimates of savings tend to be higher than empirical measurements. Similarly, Davis et al. (2014) estimate energy savings from a program to replace inefficient refrigerators in Mexico, finding that these amount to about one quarter of predicted savings. The above-cited studies on buildings retrofits also confirm that realized energy savings tend to be systematically below ex-ante estimates.

In sum, for many energy-transforming technologies, verifiability is both difficult and costly, which can explain differences in measures of energy savings before and after purchase/installation.

13. 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 turn, the credence goods model suggests that this may lead consumers to stay out of the market, reducing investments in energy efficiency. From a policy perspective, this may also induce policy-makers to incentivize behavior that is not cost-effective (Fowlie et al., 2018).

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. Experimental results suggest that the associated reduction in the expected loss by consumers nearly doubles market participation, as measured by the number of trades. Market efficiency is, however, hampered by overpricing, which is observed in 75 percent of trades.

While liability can easily be introduced in a laboratory environment, in the field it may not be feasible to rule out undertreatment (e.g. through fines). 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, Giraudet et al. (2018) provide evidence that energy savings achieved by attic insulation and duct sealing interventions are lower when installed on a Friday, and interpret this as a change in labor costs before the weekend. Despite this realization of undertreatment, it is difficult to enforce penalties for relatively low energy savings, as energy savings are affected by energy consumption which may fluctuate for exogenous reasons.

One specificity of energy-transforming technologies is that they are often sold by retailers, which act as intermediaries between manufacturers and consumers.[14] Retail agents may not be well informed about the energy efficiency of products (e_l and e_h), or be able to carry-out a diagnostic to determine the most appropriate technology. In this setting, intermediaries who cannot be made liable for false statements engage in cheap talk which can hardly influence the buyer, and may reinforce the asymmetric information problem (see Farrell and Rabin, 1996, for a discussion). Moreover, even if intermediaries are well informed about energy characteristics of products, they may choose not to disclose it to a majority of uninterested consumers (Allcott and Sweeney, 2017). As a solution, Milgrom (2008) discusses the role of liability rules for withholding information or even for not providing relevant information which the sales agent should have known, although in practice this may be difficult.

One approach to enforce liability is energy performance contracting, whereby a contractor (manufacturer or retailer) selects and installs a technology, and is subsequently entitled to a share of the financial gains associated with realized energy savings. The structure of the contract should be such that expert-sellers maximize profits by installing the cost minimizing technology (Tietenberg, 2009). Energy performance contracts would therefore make undertreatment unattractive, as expert-sellers would forgo profits associated with energy savings. Similarly, installation costs are borne by expert-sellers, which prevents overpricing. The contract may also contain incentives for expert-sellers to maintain or improve energy savings (see Sorrell, 2007).

In the context of equation (1), a performance contract can be defined as an insurance on realized energy savings, whose financial value $p_e(\hat{m}_i\hat{e}_l - \overline{m}_i\overline{e})$ is shared by contract holders. However, in practice, the difficulty to define baseline energy consumption $\overline{m}_i\overline{e}$ is an important barrier to performance contracting. While this has led the contracting industry to design standardized estimation procedure, essentially a before/after comparison with ad-hoc adjustments for the consumption of energy services (see Efficiency Valuation Organization, 2018), it can only be applied to specific

14. We thank an anonymous referee for raising this issue.

investments. 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 a changing climate may affect realized energy savings and induce a risk that the supply-side may not be willing to hold.

We conclude that liability can improve market efficiency for a limited number of energy-transforming technologies, either through regulation and fines or through energy performance contracting. However, in many cases, exogenous and endogenous variability in realized energy savings hampers the possibility to make expert-sellers liable for failure to deliver energy savings in line with ex-ante projections.

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 link it to the literature on energy efficiency. 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 information asymmetry 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, trustworthy and verifiable information on expected savings $m_i(e_l - e_h)$ (from energy labels or any other sources) would transform energy efficiency in a search good, thus reducing a key source of market inefficiencies.

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 that the driver applies a false tariff and charges extra fees increases, and these are both instances of overpricing. By contrast, consumers who use their smartphone to suggest directions to the driver, thereby signaling some degree of expertise, are less likely to be subject to overtreatment and overpricing.[15]

Labels for energy-using technologies inform consumers about energy consumption and have been introduced in many countries (e.g. U.S. Federal Trade Commission, 1979; European Commission, 2013, for the United States and the EU respectively). Empirical evidence suggests that the information transmitted on labels helps consumers to make cost efficient decisions. For example,

15. Similarly, in the medical domain, Domenighetti et al. (1993) study the frequency of common surgical procedures and show that the probability to receive a surgery is significantly lower if the patient has a physician in his family or is a physician himself, which presumably reflects lower informational asymmetry (see also Gruber and Owings, 1996; Gruber et al., 1999).

Newell and Siikamäki (2014) test alternative designs for information contained in energy labels and emphasize the importance of information on financial savings. A closely related research by Davis and Metcalf (2016) shows that providing tailored information on usage rates (m_i) results in more cost efficient choices of air conditioners.

However, supply-side incentives associated with the credence nature of energy efficiency may compromise trustworthiness of labels. Goeschl (2019) finds systematic discrepancies between self-declared e^* and verified energy efficiency ratings of refrigerators sold in the EU market ($\hat{e} - e^* > 0$), which suggest that labels are not sufficient to ensure that consumers use it as a trustworthy source of information. Following the credence goods framework, this can be related to evidence that consumers remain at least partly inattentive to this information (Sallee, 2014; Allcott and Knittel, 2019).

Trust in certification can potentially be addressed by competitor testing, whereby competing expert-sellers verify information about products of competitors (i.e. enforce liability for $\hat{e} = e = e^*$). Plambeck and Taylor (2019) show that when violations of certification lead to fines or restricted market access, competitor testing can be more effective in enforcing certification as compared to a regulator. However, entry of non-compliant firms with low-quality products is still possible when the market share of these low quality products is not sufficient to draw competitors to test the products.

Therefore, even if competitor testing is allowed, the need for a regulator to punish violation of product certification remains. Related to this, a regulator may also introduce minimum efficiency standards $\underline{e}$ in order to avoid low-quality products entering the market. Brucal and Roberts (2019) and Houde and Spurlock (2015) analyze a change on minimum energy efficiency standards for several technologies, reporting evidence that prices of the remaining products decline, while quality and consumer welfare increase. These results suggest that removing highly inefficient technologies from the market can increase overall consumer welfare.

Certification in the context of credence goods may induce expert-sellers to increase mark-ups associated with energy efficient products ($p_h - c_h$). Houde (2018) studies pricing behavior for suppliers of refrigerators who have lost their energy certification, and estimates that certification increases the price of products by 2 to 5 percent.[16] This suggests that certification on markets for credence goods can lead expert-sellers to partially appropriate expected benefits associated with lower energy consumption.[17]

Finally, we note that information may also come in the form of general recommendations such as web-based guidelines provided by the U.S. Department of Energy on how consumers can perform energy audits themselves or estimate their energy use for certain services.[18] External information on whether equation (1) is likely to hold may reduce the degree of asymmetric information when a diagnostic is performed and can be used to signal knowledge about personal needs. However, Gottschalk et al. (2020) report field evidence in the context of dental care that such information does not necessarily increase market efficiency. In particular, the authors find that patients who signal that they will obtain information on diagnostics from an internet platform do not benefit from a lower probability of overtreatment.

16. 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.

17. Note that when costs are unobserved, consumers are unable to determine whether higher prices reflect higher cost or surplus appropriation by the expert-seller. This possibility is ruled out in the setup studied in Dulleck et al. (2011).

18. 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.

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 may cause a problem of supply-induced demand (e.g. for whichever option affords higher markups).[19] This issue can be addressed by separating the diagnostic from the treatment, so that the expert performs the diagnostic (equation 1) while a seller supplies a treatment (q_h or q_l in our two goods framework). 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.[20] These results presumably reflect spiteful behavior by experts 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 an 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 overall welfare.

In the context of energy-transforming technologies, Anderson and Newell (2004) study a government-sponsored independent audit program, showing that about half of recommended energy-efficiency measures are adopted, and Fleiter et al. (2012) provide survey evidence that "consultants neutrality" is an important driver of participation in subsidized energy audits. Blonz (2019) evaluates a program to replace refrigerators among low-income households in California, finding that contractors limited to perform a diagnostic (i.e. whether the fridge should be replaced or not) are less likely to recommend replacement as compared to contractors who were further paid to replace the fridge. This can be interpreted as evidence that separating diagnostic from treatment decreases overtreatment in the context of energy efficiency investments. However, empirical evidence reported in Fowlie et al. (2015) and Fowlie et al. (2018) also confirms that households' welfare cost associated with energy audits is significant, with few households signing up for highly subsidized energy audits. In turn, as suggested by results from the credence goods literature, the overall welfare impact of audits is likely mixed (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 (e_h or e_l). 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 ($\hat{e}_h$ or $\hat{e}_l$, respectively). Allcott and Greenstone (2017) find that the sequence of audits increases the willingness to pay for unobserved (non-monetary) benefits associated with energy effi-

19. Similarly, Causholli et al. (2013) and Knechel (2013) discuss how auditing services (e.g. in the context of accounting) share the characteristics of credence goods when the audit and the treatment is performed by the same agent. They show that auditors may have incentives to under- or over-audit.

20. In this experiment, consumers can verify which treatment was provided. In combination with the parameters of the experiment, this implies that both consumers and expert-sellers benefit more from solving the high condition, so that overtreatment is expected.

ciency, 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 cost 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, such as an insurer or an employer. Both theoretical predictions and empirical evidence show 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 subsidies for energy efficient technologies (s_h), which often play an important role in policy promoting energy efficiency investments. 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.

Kerschbamer et al. (2016) provides field evidence on third party reimbursement in the market for computer repairs. When an expert-seller knows that the consumer is insured, the average bill for a pre-specified problem is EUR 129, as compared to EUR 70 when the consumer bears the full cost of the reparation. About one third of the difference is due to 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 subject to overpricing. 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.[21]

In our framework, third-party reimbursement is akin to a situation where part of p_h and p_l is not borne by the consumer. By contrast, subsidizing the energy efficient technology implies that consumers only bear $p_h - s_h$, making q_h cost-effective for additional consumers with a lower m_i (see related discussion of additionality in Globus-Harris, 2020, and Gilbert et al., 2019). 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 indicate that expert-sellers are prone to manipulate both diagnostic and delivery to appropriate (part of) the subsidy. For example, Iizuka (2007) shows that physicians who can directly sell drugs to patients are more likely to prescribe those that afford higher markups.

Subsidies may therefore affect supply-side incentives, notably through markups. While evidence on how subsidies affect market prices for energy efficient technologies is scarce,[22] Allcott and Sweeney (2017) provide experimentally controlled evidence on how subsidies and markups affect expert-sellers' behavior and the demand for water heaters. They study the behavior of sales agents in a call center who cannot manipulate prices and instead rely on sales incentives, finding a strong complementarity between financial incentives for the seller (premium for selling q_h) and those for consumers (subsidies s_h). In particular, such joint incentives increase both the probability that the

21. 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.

22. Pless and van Benthem (2019) discuss ways to prevent expert-sellers from manipulating features of solar systems in order to appropriate subsidies. See also Aldy et al. (2018) and De Groote and Verboven (2019) for a discussion of how subsidies affect investment costs and electricity production.

seller mentions financial savings associated with the energy efficient water heater and the number of sales of the more energy efficient technology. By contrast, a consumer rebate without sales incentives does not lead the seller to disclose information about financial savings associated with the energy efficient technologies, strategically marketing the energy efficient version to a small minority of responsive consumers which ultimately results in undertreatment of high usage 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 pricing and 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) find 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.[23]

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, investment decisions are infrequent, and at the individual level it is difficult to leverage reputational concerns to induce honest behavior. Nevertheless, the literature suggests that consumer learning and reputation building by expert-sellers matter for investment decisions. In the market for cars, where consumers can learn about unobserved quality attributes through the experience of other consumers (e.g. through press reports), Heutel and Muehlegger (2015) show that adoption of high quality hybrid vehicles (the Toyota Prius) propagated a signal of high quality and increased the market share of all other models of hybrids. Conversely, the Honda Insight was perceived to be of lower quality, and its adoption had a negative impact on trust for that technology, leading to lower adoption rate for all other hybrid vehicles.

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 measure of whether a given seller delivered an economically viable technology (as per inequality 1). Such information can take the form of realized financial savings by previous consumers $p_e \hat{m}_i(\hat{e}_l - \hat{e}_h)$, for example. In line with this, Gillingham and Tsvetanov (2018) study 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.

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

4. DISCUSSION AND CONCLUSION

In this paper, we have investigated the credence component of energy-transforming 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. Starting from a basic 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, as well as low market participation. We highlight the difficulty to quantify energy savings, the associated failure of both verifiability and liability for many energy-transforming technologies, 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 for researchers and policy-makers dealing with the market for energy efficiency.

We then surveyed lab and field evidence on credence goods and relate key empirical findings to the literature on the adoption of energy efficient technologies. We can summarize the implications of our work for energy efficiency policies along three main axes: (i) trustworthy certification schemes; (ii) subsidies in the presence of asymmetric information; and (iii) energy audits, reputation, and information on realized energy and financial savings.

First, we have highlighted that traditional energy labels and certification schemes involve a trust component. One implication is that third party verification of information and strict liability rules are necessary to ensure that labels provide decision-relevant information for consumers. In this context, we have discussed the role of competitor testing as an approach to detect fraudulent information provision. On the one hand, competing firms who comply with certification obligations have an incentive to make sure other firms comply as well. On the other hand, firms may be better informed than regulators as to how best perform relevant tests. Competitor testing therefore provides a promising approach to enforce liability in the domain of energy certification.

Second, evidence from credence goods markets suggests that subsidizing energy efficient technologies is likely to increase markups, and therefore trigger overtreatment of consumers. In the context of energy efficiency, subsidies may thus lead consumers to invest in technologies with negative net present values. Consequently, supply-side adjustments to higher markups can be expected to affect the welfare of consumers in relation to subsidies for energy-efficient technologies. That being said, we note that empirical evidence on how prices for energy efficient technologies respond to subsidy policies remains thin, and further research in this area is warranted.

Third, separating diagnostic from treatment can reduce inefficient behavior by expert-sellers, but the additional cost of audits can also reduce overall market efficiency. As a substitute, providing empirical evidence on realized energy savings and associated financial implications for already completed projects (as in Gillingham and Tsvetanov, 2018) may help consumers reach better investment decisions. Similarly, sharing information from ex-post audits through feedback platforms may help suppliers build a reputation. Promoting these relatively cheap sources of external information for consumers may help mitigate asymmetric information problems in the domain of energy efficiency investments.

We close by emphasizing that research in energy economics may also benefit to the wider literature on credence goods. For example, the use of performance contracting has developed for specific investments and technologies, and a number of papers in the energy economics literature discuss the market for such contracts. But performance contracting can also be applied in other contexts, and Bester and Dahm (2017) discuss the possibility to spread payments to healthcare providers over time and condition these on patients' satisfaction with the treatment. Applying a credence goods framework to study specific energy-efficient technology may therefore be useful to broaden the scope of contributions made by energy economists.

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