

Double Moral Hazard and the Energy Efficiency Gap

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Abstract

This paper proposes two contract theory-based insights into the energy efficiency gap, i.e. the debated notion that current levels of energy efficiency are too low *and* yield economic inefficiencies. It considers home energy retrofits (i.e. building envelope and heating system improvements), which provide energy savings with uncertainty because of a variety of uncontrollable factors such as weather conditions or singularities of home architecture. In this uncertain context, the quality of installation provided by the retrofit contractor is not fully observable to the homeowner. Consequently, the contractor will cut quality, which will cause social welfare losses. The paper first formalizes this moral hazard explanation for the energy efficiency gap. It subsequently shows that the energy efficiency gap is resilient to warranty insurance. Indeed, if the parties try to fix the problem by negotiating a contract that guarantees energy savings, then a second moral hazard arises: the homeowner can increase his level of energy service (e.g. indoor temperature), which is unobservable to the contractor, in order to increase warranty payout. As a result, the only contract both parties can agree upon specifies incomplete insurance, which does not restore economic efficiency.

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1. Introduction

When it first arose in the 1970s, the energy efficiency discussion was polarized between engineers' advocacy and economists' skepticism. The former pointed out the gap between current low levels of energy efficiency and greater provisions that would save on consumers' energy bills, while the latter interpreted these opportunities as "unpicked 20 dollar bills on the sidewalk" that are inconsistent with economic rationality. At the core of the "energy efficiency gap" debate lied the following question: *Do energy efficiency improvements necessarily imply higher economic efficiency?*

Two decades later, Jaffe and Stavins (1994) proposed a conceptual framework that helped answer the question by reconciling both views. They outlined the economic problems at stake and classified them according to a "market barrier/market failure" dichotomy. Market barriers can be seen as normal components of markets that, although preventing energy efficiency to be maximized, do not impair economic efficiency. As such, they do not call for government intervention. This is for example the case with consumer heterogeneity: although a widespread adoption of energy efficient devices would maximize total energy efficiency, it would certainly imply welfare losses for those people who have a weak preference for these devices. Differently, some market failures prevent both energy efficiency and economic efficiency to be maximized, hence justifying government intervention. These can occur on energy markets (e.g., environmental externalities, energy security, inadequate pricing in utilities) or energy efficiency markets (e.g., information asymmetries, split incentives, innovation externalities). The market barrier/failure framework has been recently enriched with the concept of behavioral failures to account for the increasingly observed fact that some energy efficiency decisions move away from perfect rationality (Gillingham et al., 2009).

Despite the sustained attention that has been paid to energy efficiency since then, Jaffe and Stavins' research agenda has been only incompletely developed. Research has been abundant when it comes to energy market failures and flourishing when it comes to behavioral failures. But the market failures that occur on the markets for energy efficiency still lack both theoretical formalization and empirical quantification (Gillingham et al., 2009; Allcott and Greenstone, 2012). In particular, different forms of information problems, which have long been suspected to be the most important source of these market failures (Huntington et al., 1994), have been little investigated.

Indeed, energy efficiency can be thought of as a credence good, whose characteristics remain uncertain even long after purchase (Sorrell, 2004). In this context, various information asymmetries might affect the transactions between buyers and sellers. Home energy retrofits, which represent one of the largest technical potential for energy savings (Levine et al., 2007), provide a relevant

example of this. A homeowner searching for a retrofit contractor does not know the type of the different bidders; this may give rise to adverse selection. Once he has chosen a bidding contractor, he does not observe the quality of the work delivered; this may give rise to moral hazard.

The present paper delves into the latter issue and investigates the case for moral hazard as an explanation for the energy efficiency gap in home energy retrofits. Section 2 describes the informational context inherent to home energy retrofits. Section 3 formalizes the moral hazard problem that follows and its implications at a general level. Section 4 provides numerical support. Section 5 concludes and comments on future research avenues.

2. Uncertainty and Hidden Actions in Home Energy Retrofits

In what follows, home energy retrofits through improvements to the building envelope (e.g., insulation, window replacement) and the heating system are considered. An energy retrofit realized by a contractor reduces the homeowner’s energy bill for space heating, in addition to providing him with ancillary amenities (e.g., acoustic benefits of insulation, aesthetic impact of new windows). However, since space heating consumption is determined by a wider array of uncontrollable factors, encompassing weather conditions, the singular architecture of the house, etc., no one can tell the extent to which the savings on energy bills are determined solely by the contractor’s intervention.

From both the homeowner’s and contractor’s point of view, energy consumption is therefore a random variable \tilde{e} . This variable is common knowledge to both agents, but each one can take hidden actions or ”efforts” ϵ and q to influence it. The homeowner will choose a level of energy service ϵ by setting heating thermostat to a desired indoor temperature. This action is unobserved by the contractor and a higher energy service (which would be more aptly qualified as ”diseffort”) will induce a higher expected energy consumption:

$$(1) \quad \frac{\partial \mathbb{E}(\tilde{e}|\epsilon, q)}{\partial \epsilon} > 0$$

Likewise, the contractor will provide a certain quality q in installing the energy efficient equipment. Technically, this relies on proper duct connections in the heating system or adequate connection between insulation panels. Unlike on other amenities, the impact of this effort on the energy

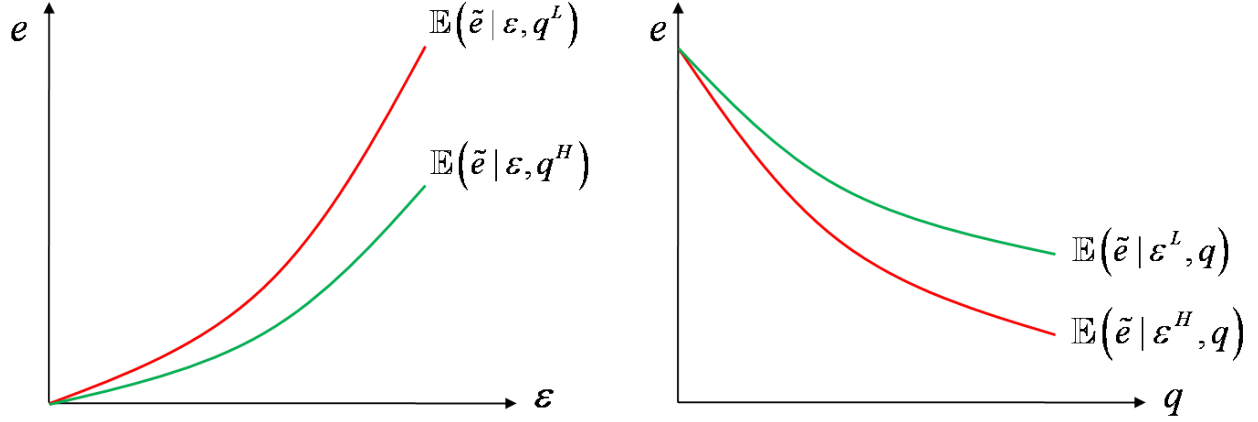


FIGURE 1. Influence of hidden actions ϵ and q on energy consumption e (with superscripts L and H denoting low and high efforts)

efficiency performance cannot be fully assessed by the consumer. The only thing that is known to both parties is that higher quality of installation lowers expected energy consumption¹:

$$(2) \quad \frac{\partial \mathbb{E}(\tilde{e} | \epsilon, q)}{\partial q} < 0$$

Further assumptions can reasonably be made that increasing energy service has a convex effect on expected energy consumption ($\partial^2 \mathbb{E}(\tilde{e} | \epsilon, q) / \partial \epsilon^2 \geq 0$), that quality has diminishing returns on expected energy savings ($\partial^2 \mathbb{E}(\tilde{e} | \epsilon, q) / \partial q^2 \geq 0$) and that both factors impede each other ($\partial^2 \mathbb{E}(\tilde{e} | \epsilon, q) / \partial q \partial \epsilon \leq 0$): the marginal increase in expected energy savings due to increased quality is larger when underlying energy service is high (e.g., a house heated in a cold climate) rather than low (e.g., a house heated in a warm climate); reciprocally, the marginal increase in expected energy consumption due to increased energy service is lower when the quality installed is high rather than low. This is illustrated on Figure 1.

¹A more general formulation of the idea behind equation (1) (resp. (2)) is that energy consumption given high energy service (resp. low quality of installation) first-order stochastically dominates energy consumption given low energy service (resp. high quality of installation).

3. Double Moral Hazard and Welfare Implications

The informational context just exposed, in which each of two contracting parties can influence the performance of a good through hidden actions, typically gives rise to a double moral hazard problem (Cooper and Ross, 1985). This can be seen in a stylized framework where both parties engaged are risk neutral.

3.1. Social, Cooperative Optimum

Assume a consumer with function $U(\cdot)$ representing concave preferences over the consumption of energy service, paying tariff T for a home energy retrofit and energy bill $P_e \tilde{\epsilon}$, where P_e is the energy price. With respect to ϵ , he maximizes a utility function $V(\cdot)$ that is separable in effort and expenditure:

$$(3) \quad V(\epsilon, q) \equiv U(\epsilon) - T - P_e \tilde{\epsilon}(\epsilon, q)$$

The firm providing the energy retrofit maximizes with respect to q the revenue from the sale minus an increasing convex cost function of the quality provided:

$$(4) \quad \Pi(q) \equiv T - C(q)$$

In a context of perfect information, the contract between the two parties will be set cooperatively and it will maximize joint expected surplus. As a result, optimal efforts $\epsilon^*(q)$ and $q^*(\epsilon)$ derived from the first-order conditions below will be such that their marginal benefit (in terms of utility to the consumer and cost savings to the firm) equates their marginal effect on consumer's expected energy bill:

$$(5) \quad U'(\epsilon) = P_e \frac{\partial \mathbb{E}(\tilde{\epsilon} | \epsilon, q)}{\partial \epsilon}$$

$$(6) \quad C'(q) = -P_e \frac{\partial \mathbb{E}(\tilde{\epsilon} | \epsilon, q)}{\partial q}$$

3.2. Private, Non-Cooperative Optimum

Now if information is imperfect, the agreement will no longer be fully cooperative. Such situation can be represented as a two-stage game in which both parties agree cooperatively on T in the first stage and take non-cooperative hidden actions in the second stage. The problem can be solved backward by simply maximizing each agent's private expected value with respect to his own decision variable, given T^2 . While this yields the same reaction function as in the cooperative agreement $\epsilon^*(q)$ for the consumer, this does not hold for the contractor. The firm will not internalize the expected benefits that its action delivers to the consumer and will simply choose the level of quality that minimizes its cost ($C'(q) = 0$). By convexity of the cost function, the firm's reaction function in the non-cooperative setting $q^{**}(\epsilon)$ will thus be lower than in the cooperative one $q^*(\epsilon)$. The intersection of $q^{**}(\epsilon)$ and $\epsilon^*(q)$ will be a Nash equilibrium. It will involve a lower consumer's energy service than in the cooperative setting, since energy service is increasing in quality, as is shown by totally differentiating equation (5) with respect to ϵ and q :

$$(7) \quad \frac{d\epsilon^*}{dq} = \frac{P_e \frac{\partial^2 \mathbb{E}(\tilde{\epsilon}|\epsilon, q)}{\partial q \partial \epsilon}}{U''(\epsilon) - P_e \frac{\partial^2 \mathbb{E}(\tilde{\epsilon}|\epsilon, q)}{\partial \epsilon^2}} > 0$$

This is a very general formalization of the energy efficiency gap: assuming away the external effects of energy consumption on the environment and other energy market failures, as well as the case for behavioral failures and risk aversion, the mere fact that energy retrofit decisions involve uncertainty and hidden actions yields losses in economic efficiency *and* too little energy efficiency (through too little quality of installation).

3.3. Warranty Insurance

To correct for this market failure, both parties may want to implement a warranty contract by which the firm bears a share s of the randomness in energy performance. In its simplest form, it reads:

²The risk-neutrality assumption causes T to not appear in the second-stage equilibrium. Note that its determination in the first stage is subject to adverse selection, which is not treated here but represents a fruitful area for future research.

$$(8) \quad V(\epsilon, q, s) \equiv U(\epsilon) - T - (1 - s)P_e \tilde{e}(\epsilon, q)$$

$$(9) \quad \Pi(\epsilon, q, s) \equiv T - C(q) - sP_e \tilde{e}(\epsilon, q)$$

Again, the implementation of this contract can be solved backward as a two-stage game played by the parties. In the second, non-cooperative stage, each party maximizes his value with respect to his own effort, given s , T and his beliefs about the other party's action. First-order conditions are:

$$(10) \quad U'(\epsilon) = (1 - s)P_e \frac{\partial \mathbb{E}(\tilde{e}|\epsilon, q)}{\partial \epsilon}$$

$$(11) \quad C'(q) = -sP_e \frac{\partial \mathbb{E}(\tilde{e}|\epsilon, q)}{\partial q}$$

Totally differentiating with respect to the decision variables and s shows that reaction functions $\hat{e}(q, s)$ and $\hat{q}(\epsilon, s)$ are both increasing in s :

$$(12) \quad \frac{d\hat{e}}{ds} = \frac{-P_e \frac{\partial \mathbb{E}(\tilde{e}|\epsilon, q)}{\partial \epsilon}}{U''(\epsilon) - (1 - s)P_e \frac{\partial^2 \mathbb{E}(\tilde{e}|\epsilon, q)}{\partial \epsilon^2}} > 0$$

$$(13) \quad \frac{d\hat{q}}{ds} = \frac{-P_e \frac{\partial \mathbb{E}(\tilde{e}|\epsilon, q)}{\partial q}}{C''(q) + sP_e \frac{\partial^2 \mathbb{E}(\tilde{e}|\epsilon, q)}{\partial q^2}} > 0$$

The implementation of such contract gives rise to a second moral hazard: the homeowner can now increase his level of energy service to increase warranty payout. This phenomenon is also known as the rebound effect. It is clear that the energy service in Equation (10) is consumed to the socially optimal level defined by Equation (5) when the consumer is not insured ($s = 0$), whereas the quality in Equation (11) is offered to the socially optimal level defined by Equation (6) when the firm offers full insurance ($s = 1$). Since s cannot be simultaneously equal to 0 and 1, insurance will not restore social optimum. In other words, the energy efficiency gap is resilient to

warranty insurance. At best, both parties will agree on an incomplete insurance contract $s \in (0, 1)$. This agreement will be a Nash equilibrium determined by the intersection of each party's reaction functions $\hat{\epsilon}(q, s) \cap \hat{q}(\epsilon, s)$. Whether it entails efforts that are lower or higher than their socially optimal value cannot be determined unambiguously at this point.

The value of s that sustains the Nash equilibrium is determined cooperatively in the first stage of the game, so as to maximize joint expected surplus:

$$(14) \quad \text{Max}_s L \equiv U(\hat{\epsilon}(s)) - C(\hat{q}(s)) - P_e \mathbb{E}(\tilde{\epsilon} | \hat{\epsilon}(s), \hat{q}(s))$$

Differentiating with respect to s

$$(15) \quad \left[U'(\hat{\epsilon}) - P_e \frac{\partial \mathbb{E}(\tilde{\epsilon} | \hat{\epsilon}, \hat{q})}{\partial \hat{\epsilon}} \right] \frac{d\hat{\epsilon}}{ds} - \left[C'(\hat{q}) - P_e \frac{\partial \mathbb{E}(\tilde{\epsilon} | \hat{\epsilon}, \hat{q})}{\partial \hat{q}} \right] \frac{d\hat{q}}{ds} = 0$$

and plugin in Equations (10) and (11) gives the equation that solves for s :

$$(16) \quad s \frac{\partial \mathbb{E}(\tilde{\epsilon} | \hat{\epsilon}, \hat{q})}{\partial \hat{\epsilon}} \frac{d\hat{\epsilon}}{ds} - (1 - s) \frac{\partial \mathbb{E}(\tilde{\epsilon} | \hat{\epsilon}, \hat{q})}{\partial \hat{q}} \frac{d\hat{q}}{ds} = 0$$

4. A Numerical Illustration

The numerical example hereafter helps visualize the different equilibria. Here energy consumption $\tilde{\epsilon}$ (in kilowatthours of heating fuel) is the product of energy service ϵ (in degrees Celcius of indoor temperature) and an inverse efficiency or "inefficiency" term (in kilowatthours per degree Celcius). The inefficiency term has a random component $\tilde{\eta}$ reflecting the uncertainty in the technical performance of the installation and it is decreasing in the quality q offered by the firm. The whole expression reads:

$$(17) \quad \tilde{\epsilon}(\epsilon, q) \equiv \epsilon \frac{\tilde{\eta}}{1 + q}$$

Elementary square root and quadratic forms are chosen for previously introduced functions $U(\cdot)$ and $C(\cdot)$, respectively. The consumer and the firm sign a warranty contract that specifies τ , a

threshold above which the firm reimburses the consumer for excess energy consumption, and s , the share of excess consumption that is then reimbursed:

$$(18) \quad V(\epsilon, q, s, \tau) \equiv \sqrt{\epsilon} - T - P_e \tilde{e} + s P_e \max(0, \tilde{e} - \tau) \equiv \sqrt{\epsilon} - T - P_e \tilde{x}$$

$$(19) \quad \Pi(\epsilon, q, s, \tau) \equiv T - cq^2/2 - s P_e \max(0, \tilde{e} - \tau) \equiv T - cq^2/2 - s P_e \tilde{w}$$

Random variable $\tilde{\eta}$ (as well as \tilde{e} for given ϵ and q) is assumed to take two values with probability p and $1 - p$. Furthermore, for given ϵ and q , the low value of \tilde{e} is assumed to not exceed the agreed upon τ , while the high one does. Additional random variables \tilde{w} and \tilde{x} are introduced for notational convenience. Overall, probability distributions are assigned as follows:

probability	$\tilde{\eta}$	$\tilde{e}(\epsilon, q) \equiv \tilde{\eta} \frac{\epsilon}{1+q}$	$\tilde{w}(\epsilon, q, \tau) \equiv \max(0, \tilde{e} - \tau)$	$\tilde{x}(\epsilon, q, \tau, s) \equiv \tilde{e} - s \tilde{w}$
$1 - p$	$\underline{\eta}$	$\underline{e} = \underline{\eta} \frac{\epsilon}{1+q}$	$\underline{w} = 0$	$\underline{x} = \underline{\eta} \frac{\epsilon}{1+q}$
p	$\bar{\eta}$	$\bar{e} = \bar{\eta} \frac{\epsilon}{1+q}$	$\bar{w} = \bar{\eta} \frac{\epsilon}{1+q} - \tau$	$\bar{x} = (1 - s) \bar{\eta} \frac{\epsilon}{1+q} + s \tau$

The first-order conditions give reaction functions $\hat{\epsilon}(q, s)$ and $\hat{q}(\epsilon, s)$, with

$$(20) \quad \hat{\epsilon}(q, s) = \left(\frac{1 + q}{2P_e[(1 - p)\underline{\eta} + p(1 - s)\bar{\eta}]} \right)^2$$

and $\hat{q}(\epsilon, s)$ solving the third degree polynomial

$$(21) \quad q(1 + q)^2 - \frac{s P_e p \bar{\eta} \epsilon}{c} = 0$$

Note that the risk-neutrality assumption causes τ to not show in these expressions. Lastly, the equivalent of Equation (16) that determines $s^\#$ reads:

$$(22) \quad s \frac{4(1 + q)^2}{(2P_e[(1 - p)\underline{\eta} + p(1 - s)\bar{\eta}])^3} - (1 - s) \left(\frac{\epsilon}{1 + q} \right)^2 \frac{1}{c(1 + 3q)} = 0$$

Reactions functions are displayed in Figure 2 with equiprobability of binary outcomes and further numerical assumptions. The cooperative, welfare-maximizing optimum would be realized when

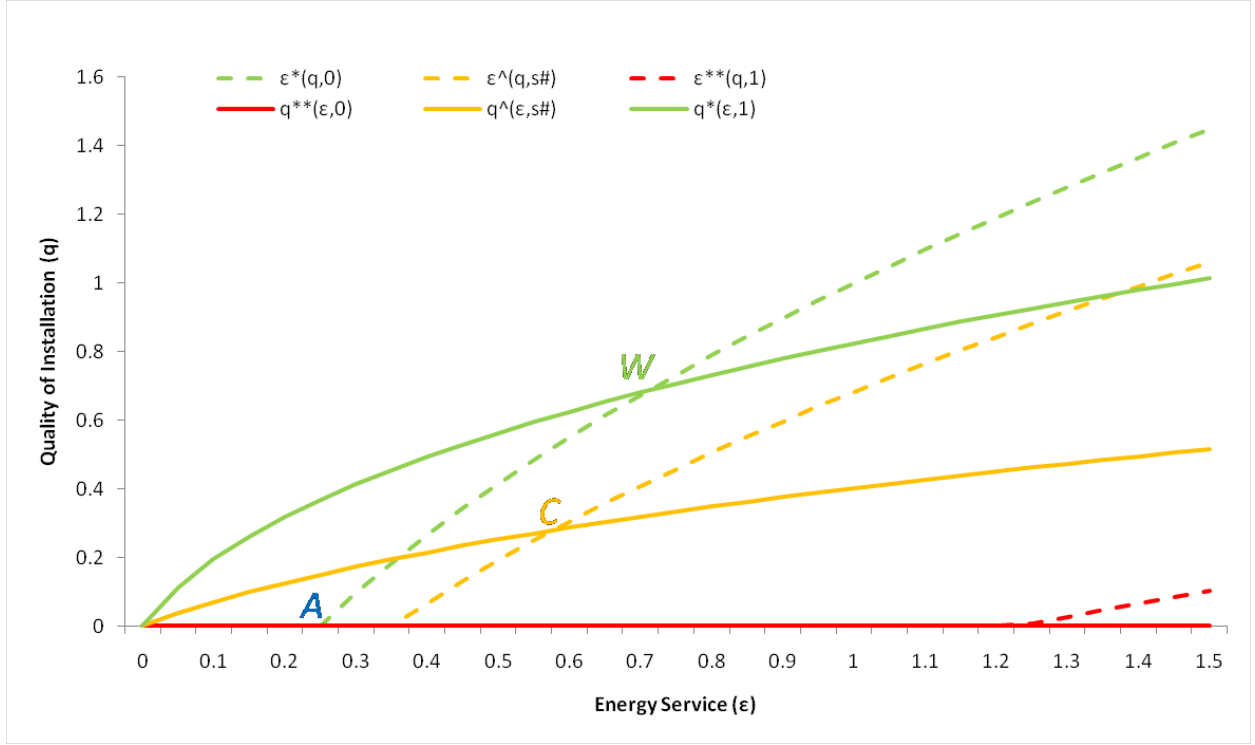


FIGURE 2. Reaction functions with $p = 0.5$, $P_e = 1$, $\bar{\eta} = 1.1$, $\underline{\eta} = 0.9$, $c = 0.2$ and $s^\# = 0.29$

$\epsilon^*(q, 0)$ and $q^*(\epsilon, 1)$ intersect at W . In the actual outcome, no insurance is implemented ($s = 0$) and the parties act non-cooperatively. This yields the same curve as in the cooperative outcome for the consumer, but a curve flat at zero for the firm. Nash equilibrium is attained when both curves intersect at $A \equiv \epsilon^*(q, 0) \cap q^{**}(\epsilon, 0)$. This yields less quality and less energy service than in the cooperative outcome. Likewise, the Nash equilibrium of the incomplete insurance contract $C \equiv \hat{\epsilon}(q, s^\#) \cap \hat{q}(\epsilon, s^\#)$ yields less quality and less energy service than the cooperative outcome.

5. Conclusion and Perspectives

This paper provides a contribution to the debate over the existence of the energy efficiency gap. It shows that if there is technical uncertainty around energy saving performance, the quality of installation offered by a retrofit contractor is unobserved to the homeowner and a moral hazard arises. As a consequence, the contractor cuts quality, which yields a socially suboptimal level of *both* energy efficiency and economic efficiency. In other words, there exists an energy efficiency gap on the markets for energy retrofits, independently of energy market failures (environmental externalities, energy security and inadequate pricing in utilities) and under fairly general assumptions of perfect rationality and risk-neutrality. The second important result of the paper is that the gap cannot be fully closed by a warranty insurance. This is because trying to solve the problem by negotiating such contract gives rise to a second moral hazard, whereby the homeowner can change his consumption behavior through actions that increase warranty payout but remain hidden from the contractor.

This starting point opens several research avenues. The most immediate one is to assess the empirical relevance of the moral hazard problem in energy retrofit decisions. Businesses have been aware of it for quite a while and energy-savings insurances or energy service companies (ESCOs) are supposed to deal with it (Mills, 2003). However, these tools have not developed as expected yet. Likewise, guarantees on energy savings are still very rare in the residential sector³. This raises the question of what are the real world difficulties in implementing such insurance contracts. A reason frequently put forward by practitioners is that most companies are too small to bear such a risk. Introducing risk-aversion in the model could be a first step to address this issue. Further complexity could be added to incorporate third party financing. Moreover, in addition to variability in technical performance, variability in energy price should be taken into account so as to figure out whether reimbursement in the contract should be based on a quantity of energy consumed or on the energy expenditure.

According to the model, since energy-savings insurance cannot fully restore economic efficiency, government intervention is warranted to foster home energy retrofits. A wide array of policies could bring the quality of installation closer to its social optimum, either through "technology push" (quality standards and certification) or "demand pull" (labels, subsidies for energy efficiency audits or any other policy that raises consumer information). On the consumer end of the double

³For an example, see: <http://www.greenhomesamerica.com/about-us/32-home-energy-audit-guarantee.aspx> (retrieved June 14, 2012)

moral hazard problem, smart meters should provide better information about energy consumption behavior. The model presented in this paper should be adapted to assess these policies. It should also integrate the environmental damages due to energy consumption, in order to assess the interactions between externality pricing and the above-mentioned policies.

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