Risk Aversion and Willingness to Pay for Energy Efficient Systems in Rental Apartments*

Mehdi Farsi

ETH Zurich, Switzerland

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Abstract

This paper uses a random utility model with a non-linear utility function to estimate the consumers' valuation of energy efficient insulation and ventilation systems in apartment buildings. Considering that the actual experience of some of these new technologies is quite limited in residential buildings, it is likely that the consumers discount the value of these systems due to uncertainty about their perceived advantages. Using the concept of certainty-equivalence, this paper proposes a model to test if the consumers show a risk-averse attitude that is specifically reserved for the acceptance of these systems. The consumers' stated choices are analyzed using their expected utility for attributes with uncertain benefits, while retaining a risk-neutral valuation of conventional goods with more or less certain benefits. The model assumes an additively separable utility function and uses a continuous link function to introduce non-linearity in the valuation of the new technologies. It is shown that the proposed non-linear formulation can accommodate the common cases of stated preference data, where the attributes are of a qualitative nature. The proposed model is applied to data from a choice experiment conducted among 264 apartment tenants in Switzerland. The findings provide suggestive evidence in favor of specific risk-aversion toward the energy-efficient systems. The analysis indicates that assuming

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symmetric risk attitudes toward new and conventional systems could bias the estimates of the willingness to pay, especially when the system is combined of several components. The estimated range of risk premiums suggests that risk considerations remain a central issue in dealing with energy efficiency in residential buildings.

Keywords: choice experiment; willingness to pay; risk aversion; energy efficiency; housing

JEL classification: Q51, C25, D12, C91

Correspondence: Mehdi Farsi, Centre for Energy Policy and Economics (CEPE), Department of Management, Technology and Economics, ETH Zurich, Zurichbergstr. 18, Zurich, 8032 Switzerland; E-mail: mfarsi@ethz.ch.

1. Introduction

The enhanced insulation and energy-efficient ventilation of residential buildings are new technologies that can considerably reduce the energy consumption for indoor heating and cooling. Cost-benefit analyses point to the economic viability of these systems even if the comfort co-benefits such as improvements in indoor air quality and protection against noise are not taken into account (Jakob, 2006; Ott *et al.*, 2006). Moreover, the empirical analyses of the few available choice experimental surveys (*e.g.* Poortinga *et al.*, 2003; Jaccard and Denise; 2006) assessed a relatively high Willingness To Pay (WTP), which would easily justify the investment in energy-saving systems. However, the actual investment in these systems is relatively rare. For instance, in Switzerland, notwithstanding several subsidy programs, the reported usage of the *Minergy* label (used for highly efficient insulation and ventilation systems) is less than 5% in new apartment buildings, and virtually non-existent in renovated buildings (Banfi *et al.*; 2008). The reasons for this 'energy-efficiency gap' are often linked with the limitations of the financial markets, the frictions in the housing markets caused by legal restrictions as well as transactions costs due to lack of information (*cf.* Jakob, 2006; Ott *et al.*, 2006).

One of the factors, hardly addressed in the previous studies, is the effect of risk-aversion in consumers' and investors' behaviors: Due to lack of information about the private and social benefits of new technologies, consumers might show a greater degree of risk-aversion as compared to ordinary systems with a widespread usage. Moreover, given the great fluctuations in energy prices the benefits of energy-saving technologies bear a relatively high risk compared to other assets.

The risk-averse behavior can be relatively easily identified in an empirical context, for instance through the concavity of the utility function. Stated Preference

(SP) methods especially choice experiments provide an interesting basis to assess the extent of risk-aversion in the individual preferences regarding new commodities such as energy efficient insulation and ventilation. Unlike the revealed preferences, in which the data on available alternatives is usually lacking, the stated choices among pre-defined hypothetical alternatives can help identify the utility function.

Previous analyses of WTP for energy-saving systems in buildings are based on linear Random Utility Models (RUM) assuming a risk-neutral behavior. In line with the few previous studies such as Herriges and Kling (1999) and Layton and Lee (2006), this paper deals with the non-linear effects in RUMs. A novelty of this paper is in applying the non-linear models within the expected-utility framework, thus allowing an inference on risk behavior. We argue that due to the inherent risks in new technologies and the uncertainty regarding their benefits, the individuals' assessment relies on their expected utility. Given that the risks are not explicitly measured and no data is available about the consumers' perception of those risks, the model relies on the concept of Certainty-Equivalent[1] (CE) to elicit the consumer's behavior facing the involved risks.

The adopted methodology also differs from most previous studies in two aspects: First, rather than the non-linear income effects, the non-linear forms are used for quality attributes of the new technologies. Namely, the utility function is linear in income and ordinary market goods. Secondly, unlike most previous studies, here the attributes cannot be represented by continuous variables that could allow an easy integration of non-linear functions. In order to overcome this problem, it is assumed that the CE value of certain 'non-market' attributes is a continuous function of the dummy variables representing different levels of those attributes. This assumption

[1] For a given risky asset and a given utility function, the CE value is defined as a risk-free asset that provides the same expected utility.

allows the specification of a ‘link’ or index function between the continuous utility function and the discrete attribute variables.

Using the data from a choice-experimental survey conducted in Switzerland, this paper analyzes the consumers’ preferences regarding energy saving systems in apartment buildings. The paper’s objectives are twofold: First, using several functional forms, we test the hypothesis of risk-neutrality and assess the potential effects of mis-specification on the WTP estimates. Second, using an appropriate functional form, we illustrate the effects of potential risks on the consumer’s or investor’s valuation of energy-efficient systems. The results suggest that risk aversion is a determinant aspect of the consumers’ behavior regarding enhanced insulation and ventilation of their residence. The risk premium entailed by the concavity of the utility function can easily attain a few percentage points with conceivable levels of variability. The WTP analysis shows that misspecification by a linear models does not create significant estimation errors for each attribute when considered separately. However, the results indicate a diminishing marginal rate of substitution suggesting a dislike for combining several attributes together, which is ignored in the linear model.

The remainder of the paper is organized as follows. After providing the general background in Section 2, the methodology and utility functional forms are presented in Section 3. Section 4 describes the data and the specification of the variables. The estimation results are presented and discussed in Section 5, and Section 6 concludes the paper.

2. Background

SP methods based on choice experiments or vignettes are increasingly commonplace in the economic evaluation of environmental goods. In these methods the experimental data fitted with a RUM are used to elicit individuals' preferences and estimate their WTP[2] for a non-market commodity or its attributes (Louviere, Hensher and Swait, 2000; Holmes and Adamowics, 2003). The SP approach can also be used for goods that have a limited or incomplete market (Bateman et al., 2002). In particular, a few studies such as Poortinga et al. (2003), Sadler (2003), Jaccard and Denise (2006) and Banfi et al. (2008), used this method to assess the consumers' valuation of energy efficient systems of heating and insulation in residential buildings.

As in most applications of the stated choice models, these studies use a linear utility function[3] usually including dummy variables for various attributes and at least one 'continuous' variable for monetary values. In linear utility models, any individual's WTP is equal to her rate of substitution of non-market commodity with the numeraire market good or money (Heshner, Rose and Greene, 2005). This is often referred to as the marginal WTP, which can be directly obtained from a given utility function (Freeman, 2003). Random utility models (RUM) are used to estimate the individuals' WTP by estimating their utility function (*cf*. Birol, Smale and Gyovai, 2006; Heshner, Shore and Train, 2005; Carlsson and Martinsson, 2001; Hanley, Mourato and Wright, 2001). In these models the utility function is elicited by comparing the random utility of chosen offers versus the not-chosen alternatives (Train, 2003; Ben-Akiva and Lerman, 1985).

The linearity assumption facilitates the estimation of WTP and the resulting welfare estimates, mainly because the effect of initial utility is canceled out and the

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[2] WTP is defined as the maximum amount that an individual is willing to bid for a public good without losing any utility, or alternatively, as the compensating variation that equates the utility with and without the non-market good, thus ensuring the same indifference curve.

[3] By linear functions I mean those functional forms whose second-order derivatives are either zero or undefined. This definition also includes the functions with dummy variables and interaction terms that are commonplace in these applications, yet are not helpful for inference about risk aversion. A better term would be *first-order* functions. However, in order to avoid any confusion with the notion of first-order risk aversion (more on this later), I prefer to use the term linear in this context.

WTP remains independent of the initial levels of consumption and income.[4] However this assumption might be unrealistic as it implies a constant rate of substitution between the non-market commodity and market goods. Especially in many cases, the marginal utility of the non-market good might decline drastically after certain threshold. For instance, the consumer's WTP for any additional measure against pollution would quickly approach zero bellow certain levels of pollution. Moreover, the consumer's attitude might be different facing the risks involved in new commodities that are not widely available in the markets as opposed to those related to market goods. Moreover, some of the widely observed disparity between WTP and willingness to accept (WTA)[5] can be related to the non-linearity of the utility function due to risk-aversion rather than loss-aversion or irrational behavior (Coursey et al., 1987). For instance a risk-averse individual, whose utility function is concave in income, will have a higher monetary equivalent for a given income gain than for a loss of the same magnitude, thus a greater WTA compared to WTP.

There is a great body of economics literature on risks and their effects on investment and consumption (*cf.* Gollier, 2001). In addition to risk-aversion, the economic literature on risks and uncertainty has brought about other notions such as prudence and aversion to ambiguity, which are likely to affect the individuals' behavior regarding environmental commodities such as energy efficiency. While prudence implies a preference for relative risks in best outcomes compared to those of worst events, ambiguity-aversion is referred to an additional dislike of assets whose risks are not known. While certain types of behavior can be relatively easily identified

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[4] Especially the independence from initial income is helpful in estimating the aggregate welfare: Hanemann (1984) shows with linear utilities, even if the individuals have different valuations of the non-market good, the expected value of WTP can be directly obtained from the ratio between the coefficients in a logit regression of the individuals' binary response for accepting/rejecting offers with given costs.

[5] WTA is defined as the minimum monetary compensation in order for an individual to give up a non-market benefit.

in an empirical context, others are more difficult to identify. For instance, risk-aversion can be identified by the concavity of the utility function as well as the consumer's systematic rejection of a mean-preserving transformation with higher variance compared to the initial asset, whereas prudence is usually associated with the signs of the utility function's third and fourth derivatives (positive and negative respectively) or systematic preference of statistical translations to the right that preserve both mean and variance (Eeckhoudt *et al.*, 1995).

Given that the data on perceived risks is difficult to obtain and clearly defined levels of risks are difficult to implement in hypothetical choice experiments, the form of the estimated utility function and its non-linearity can be used to assess the risk-averse behavior and its effects on the adoption of new technologies. A number of studies have explored the non-linear effects of income and attributes in RUMs. An important example is Herriges and Kling (1999) that provides a review of the few preceding studies.[6] Applying several functional forms including translog and generalized Leontief to sportfishing survey data, Herriges and Kling (1999) find that the possible non-linear effects are generally small and mostly dominated by the changes due to various econometric specifications. Layton and Lee (2006) and Layton (2001) are two other studies that considered several non-linear functional forms and highlighted the differences among various specifications. In particular, the former paper recommends a strategy based on averaging across different models in order to improve the WTP estimates.

Other studies focused on the non-linear effects of income: Aiew, Nagya and Woodward (2004) estimate the WTP for irradiated ground beef from a choice experiment. Using several functional forms for the income variable those authors

[6] A important contribution is McFadden (1999) who proposed a Monte Carlo simulation method for calculating aggregate welfare measures based on compensating variation in the non-linear cases. Alternative closed-form solutions have been recently proposed by Morey and Rossman (2008).

show that the differences across different specifications are not statistically significant. Using several data sets Cooper (1991) reports that the estimated mean WTP could be sensitive to the adopted functional form. Cooper (2002)[7] used semi-parametric methods to estimate the WTP from choice data with dichotomous response, but remained inconclusive regarding the non-linear effects. Semi-parametric methods allow a fully flexible functional form, but as Cooper (2002) points out, this flexibility comes at a loss of statistical efficiency and the difficulty in the economic interpretation of the estimated coefficients. Morey et al. (2003) propose a method for incorporating income effects through a piece-wise linear function that allows a differentiation between income categories or several representative consumers.

In virtually all the above studies, the non-linearity is considered for continuous variables such as income and those attributes that could be approximated as continuous variables. Moreover, the main focus of these studies lies upon the robustness of the WTP measures, and the consumers' risk attitudes toward the non-market attributes have received little attention. This shortcoming is probably related to the fact that the concept of risk-aversion is often associated with twice-differentiable and continuous utility functions. In such a framework, it might appear that the concept of risk aversion based on expected utility does not apply to discontinuous or dummy variables representing non-market attributes. Yet, it is important to note that even with dummy variables the expected utility can be defined (or approximated) as a continuous and twice-differentiable function of the CE value. Namely, even though the utility function is discontinuous or piece-wise linear, the expected utility incurred from having a commodity is a continuous variable.

[7] While Cooper (2002) applied his model to contingent valuation method, the proposed semi-parametric framework can also be used in choice experiments.

The risk-aversion concept for piece-wise linear utility functions has a fairly long history in the economics literature. This type of risk-aversion, identified by Stiglitz (1969) in the behavior of firms facing progressive tax rates, is occasionally referred to as 'first-order risk aversion,' a term coined by Segal and Spivak (1990). The latter define the first-order risk aversion as the cases in which the risk premium has a non-zero derivative with respect to the risk measure (*e.g.* variance of a payoff), which implies that even at very small risks, the decision-maker cannot be considered as almost risk-neutral.[8] An example of 1st order risk aversion is the risk-averse behavior observed when the utility function is a piece-wise linear function, but the discontinuities and the resulting nonlinearities are such that the mean-preserving spreads are systematically rejected by a seemingly risk-neutral firm (Eeckhoudt *et al.*, 1997).[9]

The form of the risk aversion considered in this paper is in some ways similar to that analyzed by Eeckhoudt *et al.* (1997) for piece-wise linear utility functions: In both cases, while in the underlying utility function the Arrow-Pratt index of absolute risk-aversion is zero everywhere except at discontinuity points, there is a positive risk premium. However, the adopted approach to specify the expected utility function differs from that paper. Here instead of calculating the expected utility by integrating probabilities with the piece-wise constant utility function, we use the concept of CE value, to ensure the continuity of the utility function. The CE value is then specified as a first-order link function of the attributes (more on this later). CE is considered as

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[8] As pointed out by Segal and Spivak (1990), the twice-differentiability of the utility function implies that at sufficiently small risks, any risk-averse person accepts a lottery with positive expected value. This restriction (countered by observations such as demand for full insurance) does not apply to a decision-maker with first-order risk-aversion, who systematically rejects sufficiently small gambles, but obviously when risks are away from zero, might have a lower or higher risk premium compared to an ordinary (2nd order) risk-averse individual.

[9] Eeckhoudt *et al.* (1997) explain how otherwise risk-neutral firms can show risk-aversion in their investment decisions should their expected net profits is a non-smooth function (due for instance, to differential tax treatment of losses and gains). The observed risk aversion could be decreasing or increasing depending upon the location of discontinuities with respect to the risk-free profit curve.

a continuous variable but as we see later, given the discrete nature of the attribute variables it can only take a finite number of values.

Focusing on the risk aversion in quality attributes rather than the non-linear income effects we propose a method to counter the difficulties entailed by discrete variables included in the utility function, while retaining linear terms for income variable and other market goods. The non-linear effect of income variable in the utility function can be interpreted as risk-aversion with respect to income or generally speaking, market goods. Given that the WTP in practical examples of public goods is generally a rather small fraction of the person’s income, one could expect that the non-linear effect of income should not be significant. That is, the small changes in the utility function due to costs of such non-market goods can be reasonably approximated by a linear function of income. Therefore, for all practical purposes to the extent that the WTP remains a sufficiently small fraction of the income, linearity (or risk-neutrality) with respect to income could remain a reasonable assumption.

Such an argument however does not apply to the benefits of the non-market good, which are generally bounded. Often times, especially in environmental goods, the marginal value of such benefits diminish considerably with the usage level. Moreover, for the benefits that are scantly known to the consumers, one can expect a risk-averse behavior namely, concavity of the utility function with respect to those attributes. Such a behavior can be considered as a relatively low marginal utility for higher levels of attributes. For instance, a consumer who does not benefit from an adequate insulation might have a relatively high marginal utility for an insulated window system or an air renewal system separately, but she might be less willing to accumulate the two systems.

3. The Model

We assume that the utility underlying the preferences of a typical individual facing the choice of a rental apartment can be defined as a function of the person's monthly income (*y*), the monthly rent (*R*), and the characteristics of the apartment. We assume that these characteristics can be classified into two groups: The first group consists of "ordinary" attributes that are reasonably well known to the consumer and are readily available in the marketplace with a competitive price. The second group includes "non-market" attributes, namely those attributes for which markets are not fully developed and/or consumers have little information. Let *X* and *Z* denote the vectors respectively corresponding to non-market and ordinary attributes of a rental apartment. These are typically binary-valued vectors consisting of zeros and ones, representing the presence or lack of the corresponding attributes. In the context of this paper, non-market attributes are enhanced insulation and ventilation systems that are relatively new in the market, while the market attributes can be considered as the conventional forms of insulation.

An offer *j* proposed to person *i* will therefore be specified as a set of three components (R_{ij}, X_{ij}, Z_{ij}) respectively representing the levels of monthly rent, non-market attributes and ordinary amenities. Assuming a multinomial logit specification the probability that individual *i*, selects a specific alternative *j* among *J* options denoted by subscript *j* = 0, 1, 2, …, *J*-1 can be written as a function of utility values obtained from each option, namely:

$$P_{ij} = \frac{\exp(U_{ij})}{\sum_{j=0}^{J-1} U_{ij}} \text{ , with } U_{ij} \equiv \mathrm{E}\left[U(y_i, R_{ij}, X_{ij}, Z_{ij})\right] . \tag{1}$$

The linear utility model assumes a constant rate of substitution between income and the non-market good. In this case *U*(.) can be replaced by a linear function. Here the idea is that in the utility function only the market attributes are readily exchangeable with money at a constant rate of substitution.[10] In the context of risks, this implies that the inherent risks involved in market goods are insignificant and comparable to those related to holding cash. It should be emphasized that the risky assets in this model namely the non-market attributes have a stochastic cash value with an expected payoff with certain risk, while the market goods are considered as risk-free assets. The valuation of non-market attributes enter with a non-linear (concave) form, implies that the consumer can show certain aversion to the inherent risks of new commodities knowing that their consequent value (comfort, cost saving, etc.) is uncertain at least relative to other conventional commodities.

Assuming additive separability[11] between the market and non-market components of the utility function, and denoting the status quo by subscript j=0, we write the utility function of Equation (1) as:

$$U_{ij} = E\left[\tilde{u}\left(X_{ij}\right)\right] + w\left(y_i - R_{i0}\right) + \beta(R_{ij} - R_{i0}) + Z_{ij}'\gamma \ , \tag{2}$$

where $\tilde{u}\left(X_{ij}\right)$ is the utility of non-market attributes X_{ij} with $\tilde{u}\left(\mathbf{0}\right)=0$, $w\left(y_i - R_{i0}\right)$ is the utility from the disposable income at the status quo rental situation, β is a the marginal value of a unit increase in rent, γ is a vector of parameters representing the valuation of the apartment's market attributes. Note that the expectation operator only applies to the non-market attributes that entail certain risks. We can assume that the utility of these attributes namely $\tilde{u}\left(X_{ij}\right)$ at any given state $X_{ij} = \mathbf{x}$ is a continuous

[10] By contrast with many WTP studies based on 'conditional' indirect utility as a function of income and unit prices (Small and Rosen, 1981), here we use the utility function directly. Therefore, income can be interpreted as a composite commodity or a numeraire good.
[11] This assumption is consistent with the findings reported by Knutson et al. (2007), suggesting that the rewards associated with a product and the losses associated with prices are processed in two distinct parts of the brain (respectively *nucleus accumbens* and *insular cortex*) and are consequently synthesized in the *prefrontal cortex* before individuals make a purchase decision.

random variable with mean $\mathrm{E}\left[\tilde{u}\left(\mathbf{x}\right)\right]$ and a variance that measures the uncertainty about the benefits of that state. The above expected utility can readily be transformed in certainty-equivalent terms as:

$$U_{ij} = u\left[\theta\left(X_{ij}\right)\right] + w\left(y_i - R_{i0}\right) + \beta(R_{ij} - R_{i0}) + Z_{ij}{}'\gamma \ , \qquad (3)$$

where $\theta\left(X_{ij}\right)$ is a scalar function (link or index function) that satisfies the following equality:

$$u\left[\theta\left(X_{ij}\right)\right] = E\left[\tilde{u}\left(X_{ij}\right)\right]. \qquad (4)$$

Notice that if u and $\tilde{u}$ are the same functions the above equality defines the certainty-equivalent value of non-market attributes X_{ij}. In order to define the risk-aversion measures, we need to impose regularity conditions on u(.) namely, being continuous and twice-differentiable. However, because of a discontinuous support due to dummy variables included in X_{ij}, the utility function $\tilde{u}(.)$ cannot be twice differentiable or continuous for that matter. An important point here is that for function $\theta\left(X_{ij}\right)$ to be the CE value, it is not necessary that $\tilde{u}(.)$ and u(.) are exactly the same function. Rather, the sufficient condition is that the certainty-equivalent condition in Equation (4) holds for all possible combinations of non-market attributes.

In fact for all practical purposes if $\tilde{u}(.)$ can be approximated by a continuous function u(.) such that the certainty-equivalent condition holds for all relevant values, the decision-maker represented by the utility function in Equation (2) can be equivalently modeled by that of Equation (3), with a continuous and twice-differentiable utility function. Therefore, in order to proceed with the analysis we require two assumptions: First, CE function is a linear function of attributes defined by: $\theta\left(X_{ij}\right)=X_{ij}{}'\alpha$, where γ is a parameter vector representing the valuation of the apartment's non-market attributes. Secondly, there exists a twice-differentiable function *u*(.) that can satisfy Equation (4) at least approximately for all possible values of X_{ij} .

By comparing the utility values on the basis of the status quo utility (U_{i0}) it is easy to see that the function *w*(.) cancels out in the econometric model implied by Equation (1). In fact, in multinomial discrete choice models it is the utility differences compared to one of the alternatives that matter, not the absolute levels. Here, the status quo can be comfortably taken as the base alternative. Equation (3) can therefore be re-written as:

$$U_{ij}=U_{i0}+u\left[\theta\left(X_{ij}\right)\right]-u\left[\theta\left(X_{i0}\right)\right]+\beta(R_{ij}-R_{i0})+\gamma(Z_{ij}-Z_{i0})\ , \quad \text{with } j=1,2,...,J-1\ . \tag{5}$$

Five different functional forms are considered for the utility function $u\left(\theta\right)$: linear, quadratic, logarithmic, power function and exponential:

$$u(\theta)=\theta\ ;\ u(\theta)=\theta+\lambda\theta^2\ ;\ u(\theta)=\ln(1+\theta)\ ; \quad u(\theta)=\theta^r;\ u(\theta)=-\exp(-\theta)\ ; \tag{6}$$

where r and λ are the model parameters to estimate. There are a few issues in the specification of the parameters in *u*(.). An obvious restriction is *u*(0)=0, implying that the additional utility from not having the non-market attributes is zero. Another restriction is an identification issue. Given that θ is defined by a fully parameterized function, $\theta\left(X_{ij}\right)=X_{ij}{}'\alpha$, no additional multiplying factor can be included in the specification of *u*().

Each one of the functions in (6) have their specific feature in the risk-averse behavior. Based on the common measures namely, Arrow-Pratt coefficients of absolute and relative risk aversion (RA) defined respectively as: $c_A \equiv -\frac{u''}{u'}$ and $c_R \equiv -\frac{u''\theta}{u'}$, the exponential function represents a constant c_A, while the power and logarithmic functions have a constant relative RA, but a decreasing absolute RA. All three forms are commonly used in the microeconomics literature. The quadratic and power functions can cover both risk-averse and risk-loving behavior as special cases, depending upon the sign of parameters r-1 and λ. The quadratic function has an increasing absolute risk-aversion, which appears to be counter-intuitive in an ordinary consumption problem. However, we retain this form, exactly because the increasing risk-aversion property might be appealing in considering the decisions about energy-efficiency. In fact, because the efficiency has an upper bound (perfect efficiency), attaining which might entail unusual sources of uncertainty due to technological constraints. These factors might justify an increasing risk aversion with the level of efficiency.

The WTP for each attribute X^k at a given initial level X_0 is defined by the corresponding increase in the utility divided by the coefficient of the rent, that is:

$$wtp^k = -\frac{u\left(X_0'\alpha + \alpha^k\right) - u\left(X_0'\alpha\right)}{\beta} , \tag{7}$$

where α^k represents the marginal value of attribute k. The WTP expression can be readily generalized to the difference between any pair of states (X_0, X_1), with the corresponding WTP expressed as: $\frac{1}{\beta}\left[u\left(X_0'\alpha\right) - u\left(X_1'\alpha\right)\right]$.

A relative measure of risk premium at any given point $X_{ij} = \mathbf{x}$ can be defined in utility terms as the difference between the expected utility and the utility of the expected attributes that is:

$$\pi \propto \frac{\tilde{u}(\mathbf{x}) - E\left[\tilde{u}(\mathbf{x})\right]}{E\left[\tilde{u}(\mathbf{x})\right]} = \frac{\tilde{u}(\mathbf{x}) - u\left[\theta(\mathbf{x})\right]}{u\left[\theta(\mathbf{x})\right]}. \quad (8)$$

$u^{-1}\left[\tilde{u}(\mathrm{x})\right] - \theta(\mathrm{x})$ However, in our case as we do not estimate the utility function $\tilde{u}(.)$ a more convenient measure can be specified as:

$$\pi = \frac{\mathrm{E}\left[m(\mathbf{x})\right] - \theta(\mathbf{x})}{\theta(\mathbf{x})}, \quad (9)$$

where $m(\mathbf{x})$ is a monetary measure of **x**, with the same units as $\theta(\mathbf{x})$, that can be specified as: $u^{-1}\left(\tilde{u}(\mathbf{x})\right)$, where $u^{-1}(.)$ is the inverse function of $u(.)$.

The above expression is especially useful because with some assumptions numerical values can be estimated for the risk premium. In fact, when functions *u* and θ are identified, for a given level of attributes $X_{ij} = \mathbf{x}$, we can simulate a random variable $\tilde{u} \equiv \tilde{u}(\mathbf{x})$ with mean $\mu = \mathrm{E}\left[\tilde{u}\right] = u\left[\theta(\mathbf{x})\right] = u\left[\mathbf{x}'.\alpha\right]$, and standard deviation $\sigma = \delta.\mu$ for a given variability ratio δ. Assuming a normal distribution (for instance), the expected value of the attributes at **x**, can be calculated as:

$$\mathrm{E}\left[m(\mathbf{x})\right] = \int_{-\infty}^{+\infty} u^{-1}(t).\varphi\left(\frac{t-\mu}{\sigma}\right).dt, \quad (10)$$

where $\varphi(.)$ is the *pdf* of the standard normal variable. The numerical values of the above integral can be calculated using the Monte Carlo simulation technique and the value of relative risk premium can be estimated for different variability ratios.

4. Data and Specification

The data used in this paper are based on the choice experiment conducted in 2003 in Switzerland and reported by Banfi et al. (2008) and Ott et al. (2006). This paper focuses on the tenants of apartment buildings. The respondents were selected among households that had recently moved in their dwellings. The sampling procedure used in the survey is based on stratified sampling to ensure the existence of a sufficient number of new buildings that are more relevant for energy-efficient technologies, and also of those buildings equipped with these systems. On average about 20 percent of the respondents in the sample have already certain experience in using the energy-efficient systems. It is therefore expected that compared to the Swiss population the sample has an over-presentation of individuals with a fairly good knowledge of the benefits of these technologies. This might result in an understatement of the risk-averse behavior, but also might cause an overstatement of the WTP for policy conclusions.

The respondents were repeatedly offered an alterative housing with various levels of energy-saving systems and were asked if they would prefer the offered alternative to their Status Quo (SQ). In each choice situation the respondent was provided with a choice card including the characteristics of the offered alternative along with those of their actual housing. These characteristics consist of monthly rent, window and facade insulation each defined in four levels (none, low, standard, enhanced) and ventilation (with or without air renewal). The alternatives are constructed by improving or deleting some of the actually available amenities. The alternative's monthly rent is specified based on the modifications of the status quo considering a decrease or increase of 0 to 25 percent of the actual rent (ranging mostly from -300 to 300 Francs per month). A factorial random design has been used to assign the levels of attributes and rents in various alternatives.[12]

The final sample consists of 3,861 observations from 264 respondents. Table 1 provides the descriptive statistics of the main variables included in the analysis. The

[12] See Banfi et al. (2008) for more details about the experiment design.

non-market attributes (vector *X*) consists of three dummy variables representing energy-efficient ventilation and enhanced window and facade insulation. The ordinary attributes (vector *Z*) include four dummy variables for the six remaining insulation categories for windows and facade. It is interesting to note that because of the linearity of the effects of rent and market attributes (*R* and *Z*), for these variables it is the relative differences not the initial levels that matter.

Table 1: Descriptive statistics

	Status Quo		Hypothetical Offers	
	Mean	Std. Dev.	Mean	Std. Dev.
Monthly rent (Swiss Francs)	1'660	907	1'606	893
Enhanced window insulation (triple glazing)	0.144	0.352	0.244	0.430
Standard window insulation (rubber sealing)	0.682	0.467	0.327	0.469
Low window insulation (old)	0.144	0.352	0.215	0.411
Non-insulated windows (very old)	0.030	0.172	0.213	0.410
Enhanced facade insulation	0.212	0.410	0.234	0.423
Standard facade insulation	0.394	0.490	0.402	0.490
Low facade insulation (newly repainted)	0.121	0.327	0.171	0.376
Non-insulated facade (old)	0.273	0.446	0.193	0.395
Ventilation (air renewal system)	0.193	0.396	0.672	0.469
New building (constructed after 1995)	0.409	0.493	–	–
Alternative rent is lower than the S.Q. rent	–	–	0.477	0.500
Alternative offer strictly dominates S.Q.	–	–	0.178	0.383
Positive response (alternative offer chosen)	–	–	0.225	0.417
Number of choice cards per respondent [a]	14.63	2.40	–	–
Number of cards with positive response [b]	3.28	3.16	–	–
Number of observations	264		3'861	

[a)] Number of choice cards varies from 11 to 18.
[b)] Number of cards with positive response varies from 0 to 14.

An asymmetry in the respondents' preferences observed in the experimental data used in this paper has been reported in Banfi et al. (2008), in that the individuals who are currently using an attribute show a relatively high valuation of that attribute. These results are consistent with several previous studies (Horowitz and McConnell, 2002 and Sayman and Öcüer, 2005) that observed a disparity between WTP and WTA. Moreover, individuals have a tendency to choose their SQ over the hypothetical offers even in cases that the offers seem to be favorable, suggesting a disutility from changing the SQ.

In this paper, assuming that the asymmetry effect is driven by an attachment to SQ as well as a difference in marginal effects of income (rent), the effect is modeled through differentiating the regression coefficient of the monthly rent depending on the location (in the space of price and attributes) of the SQ compared to the hypothetical offer.[13] Namely, in addition to a dummy variable representing the SQ, two interaction terms with the rent variable are also included. By including these interactions, we expect that the main price coefficient be abstracted from the endowment effect[14] and the SQ inertia. The first interaction term is applied to cases when the hypothetical offer has a lower price compared to the SQ rent. Whereas the second term is used to differentiate the marginal value of money when the (hypothetical) alternative strictly dominates the SQ situation, that is, an apartment with strictly better attributes is offered at a strictly lower price. The data indicate that probably because of the disutility of any change (moving apartments), these cases do not systematically receive positive response. However, these cases cannot be pooled with those cases that appeal to endowment effect. In fact, the regression results suggest that the respondents show a relatively high responsiveness to prices in these cases compared to the endowment-effect situation.[15]

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[13] See Scarpa *et al*. (2005) for a discussion of various methods of modeling the status-quo effects.

[14] The endowment effect is the commonly observed effect in which the decision maker shows a relatively high valuation of a commodity (or low value for money) when she is to lose that commodity.

[15] Following Scarpa *et al*. (2005), we also considered several alternative specifications that include additional interaction terms for various attribute variables. The results (available upon request) show that these effects are generally insignificant, unless the price interactions were excluded. This might suggest that the available data does not allow a sensible differentiation of WTA from WTP for each attribute. Noting that the WTA discussions are beyond the scope of this paper, we decided to restrict the interaction terms to price variables.

5. Results

The regression results obtained from models 1 to 5 are provided in Table 2. These results are obtained by maximum likelihood method. Model 1 is the conventional linear model. Overall, the results in terms of sign and significance are plausible across all the models. As expected the negative effect of the SQ variable indicate a significant reluctance against change, the positive effect of the first interaction term indicates a considerably lower responsiveness to decreasing prices, suggesting a strong endowment effect. However, when the alternative offer dominates the SQ, the respondents show relatively more responsiveness to prices, as indicated by the negative value of the second interaction term.

Table 2: Regression results

	Model 1 Linear	Model 2 Quadratic	Model 3 Logarithmic	Model 4 Power	Model 5 Exponential
Monthly rent (Swiss Frs)	-.0063 ** (.0006)	-.0063 ** (.0006)	-.0059 ** (.0006)	-.0063 ** (.0006)	-.0054 ** (.0005)
Monthly rent × (alternative rent is lower than the SQ rent)	.0052 ** (.0008)	.0051 ** (.0008)	.0052 ** (.0008)	.0052 ** (.0008)	.0054 ** (.0008)
Monthly rent × (alternative offer strictly dominates the status-quo)	-.0018 ** (.0006)	-.0018 ** (.0006)	-.0027 ** (.0005)	-.0018 ** (.0006)	-.0047 ** (.0005)
Ventilation (air renewal system)	.5302 ** (.081)	.5718 ** (.093)	.7610 ** (.164)	.5391 ** (.095)	.3652 ** (.114)
Enhanced window insulation (triple glazing) [a]	1.647 ** (.155)	1.948 ** (.283)	6.373 ** (1.419)	2.132 ** (.373)	13.556 (111.0)
Standard window insulation (rubber sealing) [a]	1.288 ** (.130)	1.2823 ** (.130)	1.1329 ** (.127)	1.2886 ** (.130)	.6170 ** (.083)
Low window insulation (old) [a]	.5916 ** (.123)	.5876 ** (.123)	.4845 ** (.119)	.5894 ** (.122)	.1695 * (.103)
Enhanced facade insulation [b]	.7973 ** (.155)	.9583 ** (.206)	1.5444 ** (.459)	.9972 ** (.224)	.4019 * (.228)
Standard facade insulation [b]	.6098 ** (.117)	.6112 ** (.116)	.3613 ** (.091)	.5954 ** (.116)	.1088 (.075)
Low facade insulation (newly repainted) [b]	.3751 ** (.104)	.3728 ** (.104)	.2762 ** (.100)	.3625 ** (.104)	.1720 * (.095)
Status quo indicator	-1.323 ** (.096)	-1.337 ** (.097)	-1.301 ** (.094)	-1.344 ** (.097)	-1.192 ** (.091)
λ (coefficient of the quadratic term)		-.0438 * (.024)			
r (exponent of the power function)				.831 ** (.082)	
Log likelihood	-1691.9	-1691.0	-1698.9	-1689.9	-1725.4
AIC (Akaike Information Criterion)	3405.9	3406.1	3419.8	3403.9	3472.7
BIC (Bayesian Information Criterion)	3474.7	3481.2	3488.6	3479.0	3541.6
HQC (Hannan-Quinn Criterion)	1713.1	1712.1	1720.0	1711.1	1746.5

a) The omitted window category is non-insulated windows (very old).
b) The omitted facade category is non-insulated facade (old).
** significant at p<.05; * significant at p<.10; Standard errors are given in parentheses.

The estimation results indicate a reasonable explanatory power for all adopted models. The overall rate of correct prediction[16] of the respondents' choices in the sample is about 80% for the three models with linear, quadratic and power functional forms and 73% for the remaining two models. The exponential model showed some numerical problems and certain sensitivity to the initial values, which could be explained by the fact that the likelihood function can have undefined values at zero

[16] A predicted probability of greater than ½, of accepting the offer is considered as positive response.

values for attributes. This model (Model 5) along with the logarithmic model (Model 3) show a relatively poor performance as regards to log-likelihood and the conventional diagnostic criteria as listed in Table 2. The remaining models are quite comparable in terms of results and prediction power. However, Model 4 (power function) can be singled out: The likelihood ratio test rejects at 5% significance level, the linear model in favor of this model (χ^2=4.025). Moreover, according to two of the three conventional criteria namely, AIC and HQIC Model 4 outperforms all other models.

The results (Table 2) also provide evidence against the risk-neutrality hypothesis, for the null hypotheses H_o: λ=0 and H_o: r=1 are both rejected respectively in Models 2 and 4. Especially the evidence is stronger in Model 4 that rejects the null at 5% significance level. Considering these results, Models 4 along with the linear model are retained for the rest of our analysis. The estimated values of WTP based on these two models are listed in Table 3. The upper panel provides the WTP for amenities that are relevant to new buildings (approximately those constructed after 1995), which we labeled as non-market or new technologies, whereas the lower panel lists the numbers related to the ordinary insulation systems that exist in virtually all Switzerland's residential buildings constructed after 1995.

Table 3: Estimates of willingness-to-pay

		Model 1(Linear)			Model 4 (Power)		
		Min.	Mean	Max.	Min.	Mean	Max.
Improvements in new buildings	*Initial status*						
Ventialtion	Enhanced	2.8	4.2**	5.6	1.2	2.9**	4.5
Ventialtion	Standard	2.8	4.2**	5.6	3.1	4.7**	6.3
Window enhanced insulation	Enhanced	1.5	2.8**	4.2	0.2	1.8**	3.5
Window enhanced insulation	Standard	1.5	2.8**	4.2	2.3	4.7**	7.0
Facade enhanced insulation	Enhanced	0.1	1.5**	2.8	-0.8	0.7	2.2
Facade enhanced insulation	Standard	0.1	1.5**	2.8	0.9	3.2**	5.4
Window & facade enhanced insulation	Standard	2.4	4.3**	6.3	3.3	5.5**	7.8
Full enhanced insulation & ventilation	Standard	6.1	8.5**	11.0	6.0	8.4**	10.9
Improvements in old buildings	*Initial status*						
Window standard insulation	Low	5.7	8.5**	11	5.7	8.5**	11.3
Facade standard insulation	Low	-0.1	2.9*	5.8	-0.1	2.8*	5.8
Window low insulation	Poor	4.2	7.2**	10.2	4.2	7.2**	10.2
Facade re-paint	poor	1.9	4.6**	7.2	1.8	4.4**	7.0

** significant at p<.05; * significant at p<.1.
WTP estimates are given as percentage of the average monthly rent (New: 2000 Frs; Old: 1300 Frs).
The minimum and maximum values correspond to the 95% confidence interval.

Jakob (2006) provides a summary of the actual costs of each one of these improvements, which can be used as a comparison basis for the plausibility of the WTP estimates. However, as pointed out by that author transforming the costs to monthly annuities relies on several assumptions about the discount rate and the building's lifetime as well as the apartment's characteristics. While such a discussion is beyond this paper's scope, it is worth noting that the estimated WTP values are quite comparable to the estimated costs. It is also interesting to note that while for the ordinary improvements (from low to standard) the WTP estimates are generally (but slightly) higher than the corresponding costs, for energy-efficient systems the ordering could be easily reversed depending on the adopted assumptions.[17]

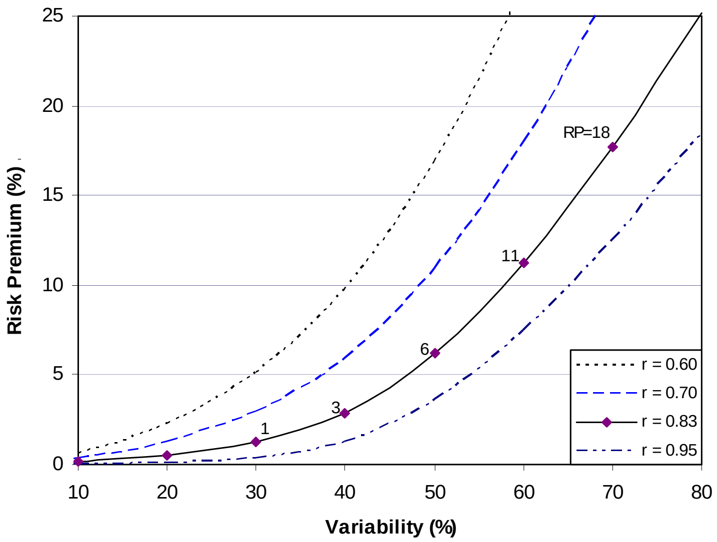
[17] For instance a typical cost estimate of updates as a percentage of the monthly rent is about 5% for window (or facade) enhanced insulation and 8% for ventilation, and about 4% for updating low to standard insulation of windows (or facade). Repainting facade costs only about 1 or 2 percent, in which case the high WTP reflects the consumers' valuation of esthetics. Because of the large variety of old windows, such comparisons are not sensible for updates in poorly insulated windows. See Jakob (2006) and Ott *et al.* (2006) for more details.

As shown in Table 3, the linear model's estimates of WTP are independent of the initial status. The non-linear model however, can distinguish between the WTP for each attribute separately. For instance, if we consider an improvement from standard insulation to a fully efficient system, the total WTP estimate from both models is about 8.5 percent. According to the non-linear model (Model 4) being initially at standard insulation, the consumer values both ventilation and window (enhanced) insulation at about 4.7%, but the facade improvement comes at only 3.2%. Now if the individual decides to improve the windows, further improvement of the facade does not provide any statistically significant value (WTP=0.7%) in the non-linear model, but has 1.5% WTP in the linear model. The non-linear model shows that the same individual will have 2.9% WTP for ventilation system (as opposed to 4.2% from the linear model). If these numbers can be used as a guide for policy programs for promoting energy-efficiency, the state should subsidize only certain forms of the improvements (for instance facade insulation) or sets the subsidies conditional on an entire improvement in all attributes.

Overall the results suggest that misspecification of a risk-averse behavior with a linear utility model, might result in misleading estimates for certain attributes, especially if individuals consider the attributes separately rather in single packages. In general, the non-linear model highlights the diminishing marginal utility of the attributes. The non-linear model shows that as the level of energy efficiency increases the valuation of further improvements decreases substantially. In principle modeling the varying rate of substitution would be alternatively possible by constructing appropriate interaction terms with the SQ levels of attributes. However, from a practical viewpoint, depending on the number of categories such a strategy might lead to an excessively large number of regression parameters[18] and in most cases, could cause difficulties in interpretation of the results.

Figure 1 depicts the estimated relative Risk Premium (RP) based on Model 4 (power function) for enhanced insulation and ventilation.[19] The numerical values are obtained from Equations (9) and (10) assuming a normal distribution for the utility $\tilde{u} = \tilde{u}(\mathbf{x})$, of having all the attributes, with mean $\mu = (\mathbf{x}'.\alpha)^r$, and standard deviation $\sigma = \delta.\mu$, where the variability ratio δ, can be considered as a measure of risk. This risk is the inherent risk in the decision maker's perceived utility (cash payoff) of the energy-saving attributes. RP values are plotted as a function of δ, for several values of r. The solid line shows the estimated values based on the data with r=.831.

Figure 1: Risk premium for enhanced insulation and ventilation



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[18] For instance for 3 binary variables the number of additional interaction terms will be 15, including 3×3 second-order and 3×2 third-order terms.
[19] RP values for other categories of attributes (as in the upper panel of Table 3) show a very similar pattern to that shown in Figure 1.

As illustrated in the figure, the model predicts about 0.5% risk premium for variability of 20% in the perceived utility around its expected value. But the RP increases quickly as this variation increases, with a value of 1.2% for 30% risk to a staggering value of 25% risk premium for a rather extreme variability of 80%. What values can be considered as reasonable risk is an interesting question for further research. However, it should be noted that the risk involved in the perceived benefits of energy-efficient systems most probably depends on the decision maker's knowledge about these systems as well as the risks involved in energy prices. A variability of 50% in a normal distribution implies that the utility can vary with 95% confidence, roughly between zero and two times the expected utility. To understand the importance of the issue, let us consider this risk as a reasonable value, in which case the predicted risk premium (6.2%) has important policy implications. If we extend this risk-aversion to investment decisions, this implies that energy efficient systems in residential buildings need to have about 6% extra return (compared to interest rate on safe assets), in order to be economically viable.

Figure 1 also shows that the RP values can vary considerably with the model parameter r, which represents the degree of relative risk aversion (Arrow-Pratt coefficient $c_R=1-r$). For instance, if we consider $r=.7$, even 30% variability leads to a risk premium of 2.9%, whereas 50% variability will result in 11% risk premium. Even if we consider a value close to risk-neutrality (say $r=.95$), 50% variability implies 3.6% risk premium. While these results indicate the sensitivity of RP estimates, suggesting excessive premium in worst cases, the overall result remains valid that even with optimistic assessments, the risk aversion is an important issue for energy-efficiency.

6. Conclusion

This paper proposes a methodological framework to consider the non-linearity of the utility function in terms of non-market goods that are defined by qualitative discrete variables. This is the case of many non-market, public and environmental goods that are not divisible and are consumed only once. The proposed models have important applications in choice experiments conducted for the evaluation of new goods because the consumers could show a risk-averse behavior due to lack of information on the potential benefits. Moreover, such models can solve the general shortcoming of the linear models in assuming constant rate of substitution between non-market goods and other commodities. Such behaviors should be modeled by non-linear functional forms. In particular, the linearity assumption appears to be too restrictive for exploring some of the peculiarities observed in choice experiments such as disparity between willingness-to-pay and willingness-to-accept.

The proposed model is applied to experimental data from a survey about the use of energy-efficient ventilation and insulation measures in apartment buildings. Most of these systems are new technologies that are not widespread in the markets. The purpose of this exercise is to estimate the consumers' willing-to-pay for these systems, but also to explore if the data provides any evidence of risk-averse behavior. An important assumption is that the non-linear effects of income and all other market goods are considered as insignificant compared to the risks involved by the non-market goods, namely, the enhanced insulation and ventilation systems. This implies that the decision of adopting these technologies has only a marginal effect on the individual's overall income, thus justifying a linear effect for income

Using the results one can reject the null hypothesis of risk-neutrality. The results also suggest that the assumption of constant rate of substitution between market goods and new technologies implied by linear models could result in misleading estimates of willingness-to-pay especially if the valuation of the attributes is considered separately. The estimated results are also used to assess the extent of potential risk premium that the consumers consider for the energy efficient systems. The results point to a significant relative risk premium even if the perceived risks are within reasonably low margins.

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