universität wien

DIPLOMARBEIT

Titel der Diplomarbeit

„At what level does risk aversion affect the investment into a passive house under uncertain energy prices?“

Verfasser

Alexander Penzias

angestrebter akademischer Grad

Magister der Sozial- und Wirtschaftswissenschaften
(Mag. rer. soc. oec.)

Wien, 2012

Studienkennzahl lt. Studienblatt:	A 157
Studienrichtung lt. Studienblatt:	Diplomstudium Internationale Betriebswirtschaft
Betreuer / Betreuerin:	Univ.-Prof. Dr. Franz Wirl

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1. Introduction

With rising temperatures and changing weather conditions all around the world it is starting to become clear that human kind has to take action and find ways to reduce its carbon footprint. Over the last few decades a lot of research has been done to try and invent a house which is more friendly from an environmental point of view compared to normal buildings and houses. One of the most important ways to achieve this goal is by trying to reduce the amount of energy needed in homes and by trying to replace the energy required with energy that is produced in an environmental friendly way. Additionally, homes are being built more and more with environmental friendly construction materials as ordinary construction materials have a high carbon footprint.

Why human kind has to reduce its ecological footprint and why passive houses are one of the many ways by which human kind can and should reduce its carbon footprint shall not be further discussed in this paper. The main goal is to analyze the decision of a human being to invest into a passive house. The question which shall be investigated is how risk averse a person must be (in a standard, real life scenario) that it will invest into a home with passive house standard as a result of uncertain energy prices in the future.

The scenario under which the investment shall be made is that an individual wants to construct a house and has the option to choose between investing into a standard home and investing into a home which has only very little heating requirements and complies with the Austrian "Energieausweis" standards. The latter is to be called a passive house. Additionally, it is important to state that the investment has to be made and the individual is to choose between either, postponing the investment shall not be an option.

The paper is structured as follows:

In chapter one and its sub-chapters a definition of a passive house according to Austrian and German understanding shall be presented. Furthermore the passive house standard in Austria will be highlighted and brief information will be given on where the "Energieausweis" and its standards are anchored in the Austrian legislation.

Chapter two will shortly explain the concept of risk aversion in utility functions. However, the main part of this chapter will be to present empirical findings in related literature in order to give an idea as to where this paper shall fit in.

Chapter three will explain the idea behind the mathematical model and how it works. First the type of utility function that will be the framework of this model, constant relative risk aversion (CRRA), will be explained and afterwards the concept of Brownian Motion will be highlighted as the energy price will be subject to uncertainty. The last part of Chapter three will explain how these two concepts are going to be combined and where and how the Brownian Motion and CRRA will come to use in the model.

Chapter four will discuss the parameters and the values they will be set at. The goal is to set them as realistic as possible in order to get a meaningful and representative value for relative risk aversion.

In chapter five the outcome of the model will be discussed and analyzed. Furthermore, a few sub-scenarios will be presented in order to show how relative risk aversion will depend on the change of some of the variables in the model.

Chapter six will give a conclusion to the findings.

1.1. Definition of a Passive House

A building which corresponds to the passive house standard is defined by providing comfortable indoor climate in summer as well as in winter without the requirement of a separate heating system to ensure thermal comfort. The airflow in a passive house as well as the insulation both play a very important role in keeping the temperature within the building constant and comfortable. Prof. Dr. Wolfgang Feist, the person responsible for the research and construction of the first passive house in Darmstadt, in 1991, defined the passive house in the following way:

> "The passive house is the result of the further development of the low-energy house. The key components are the excellent heat protection, very good airtightness and passive houses' highly efficient heat recovery from exhaust air. A conventional heating system is superfluous due to the combined use of internal and solar heat gains. The passive house concept leads to the highest degree of comfort with minimal energy consumption."[1]

As can be seen in **Fig. 1**, the market for passive houses is just at the beginning but the demand for homes with this new ecological standard will rise dramatically. Note that the area fully colored in red represents the cumulated best case scenario for old buildings which are going to be upgraded to achieve passive house standard and the area colored in blue represents the cumulated best case scenario for newly constructed buildings which fulfill the criteria to be called a passive house. The blue and red lines represent the "business as usual" scenario, respectively.

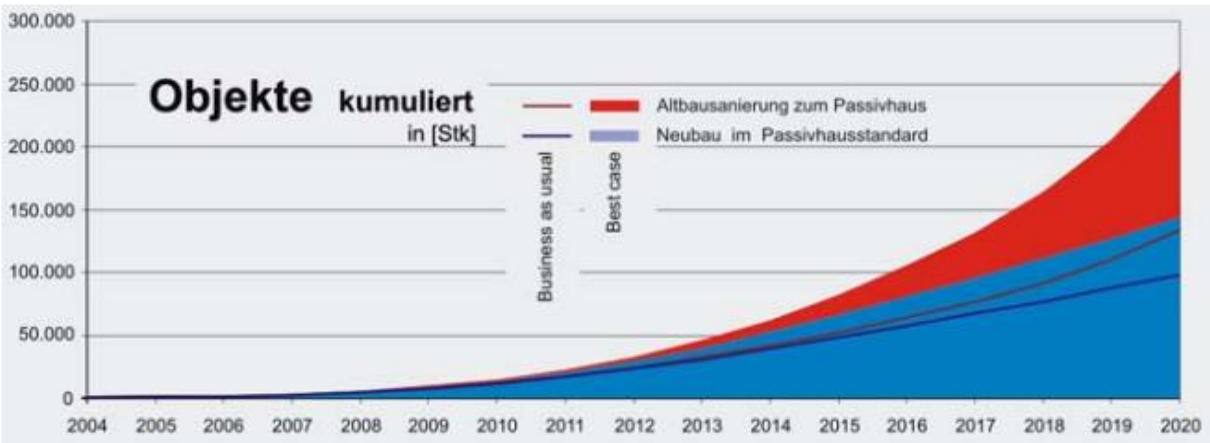

Figure 1: Prognose Passivhaustrend bis 2020 as by (IG Passivhaus Österreich, 2006)

[1] (Pokorny et al., 2009, p. 14)

1.2. Requirements for the Passive House Standard in Austria

In Austria the energy standards were implemented through the EAVG (Energieausweisvorlagegesetz) on the 3rd of August 2006 as a result of the EU building guide lines which came into existence in 2002. According to the ÖNORM H 5055 every building (a few exceptions do exist) has to have a so called energy pass which gives information about its heating requirement. An example of such an energy pass (as it is defined by the OIB-Richtlinie 6) can be seen in **Fig. 2**. This figure is part of an example of how the energy pass can look like which was shown by the Austrian

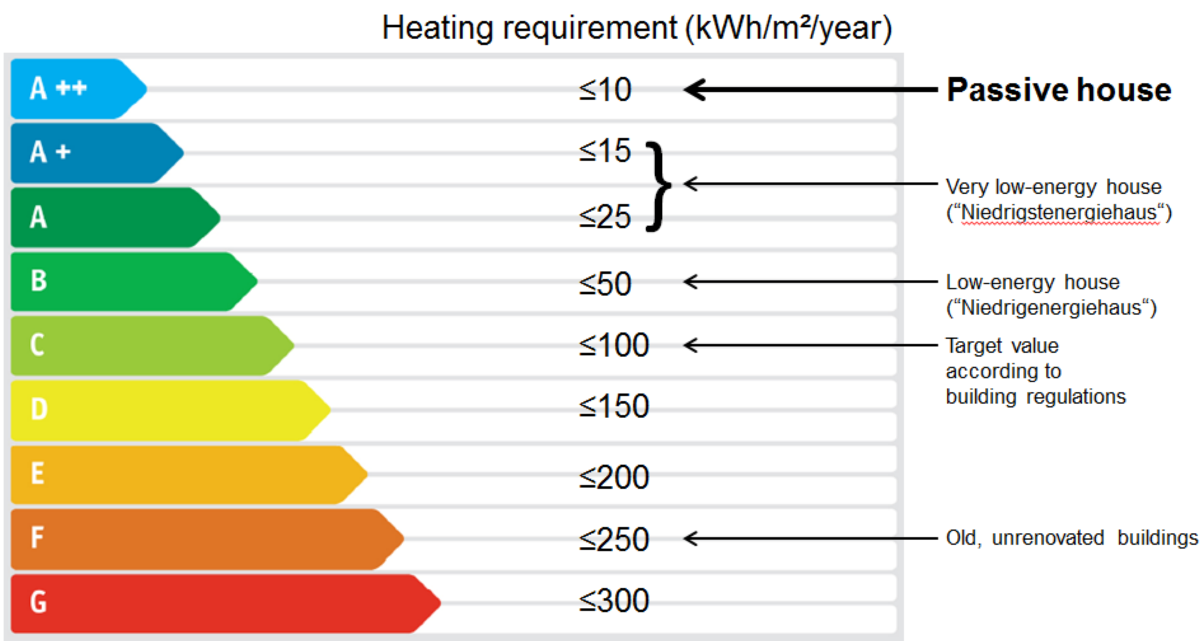

Figure 2: Categories of heating requirements of buildings as by the (Austrian Institute of Construction Engineering, 2007)

Institute of Construction Engineering. The heating requirement of the Austrian energy standards is specified in kWh per square meter per year. The Austrian institute for civil engineering is assigned with the coordination and implementation of such guidelines on a state level. The following heating requirement classification was defined by the Austrian Institute of Construction Engineering (2007, p. 8,9). Building regulations in Austria try to target heating requirements of 100 kWh/m²/year but obviously this value is not always achievable and especially dependent on the behavior of the inhabitant. For old, unrenovated buildings the heating requirements can lie somewhere between 150 kWh/m²/year and 300 kWh/m²/year which would put them in the energy classes between D and G. Buildings which use less or equal to 50 kWh/m²/year are in the class B and are called "Niedrigenergiehaus". Buildings with a heating requirement between 15 kWh/m²/year and 25 kWh/m²/year are called "Niedrigstenergiehaus" and the corresponding classes are A and A+. The highest energy standard, A++, means that a building requires less or equal to 10 kWh/m²/year and this is the passive house standard.

2. Risk Aversion and Utility Functions

In brief, a utility function explains how satisfied a person is by, for example, consuming a good or how satisfied a person is with receiving a certain salary. It seems obvious that it is impossible to find out or guess the utility function of every human being but one can try and develop a function which could be used to explain certain behavior of an aggregation of human beings.

If, however, an individual is to choose between two alternatives and at least one alternative has uncertainty attached to it one cannot simply calculate the utility of the option which has a probability incorporated. In this case economists speak of a lottery and in order to find the correct utility it is necessary to apply the concept of expected utility where each possible outcome is weighted by its probability and then every outcome is added up to express the expected utility of an option.

However, this kind of utility function is not enough to be applied in reality as it implies that an individual does not incorporate risk into its decision. Because human beings are not often rational thinking it is important to incorporate their affinity (or aversion) towards risk and uncertainty into the decisions which have to be made.

Upon encountering uncertainty the degree of risk aversion tells us how an individual will react to this risk. In brief: the utility function (depicted on a two dimensional graph where the vertical axis represents the utility and the horizontal axis represents the amount of risk) of a risk averse individual is concave, i.e. the utility of a higher payment (with higher risk) is higher than a utility of a lower payment (with lower risk) but the increase of utility does not happen one to one with the increase in risk. This means that the higher the risk of a payment the smaller the marginal increase of utility. Additionally, at a certain point of the utility curve the risk premium will tend to get very high although the payment only increases very little.

A risk neutral person's utility function is a straight line at a 45° angle which means that the utility of the uncertain payment increases one to one with the increase of the payment itself, thus implying that a risk neutral individual does not require a risk premium for increasing risk.

A risk affine individual has a convex utility function and the expected utility of payment increases at a higher rate than the increase of the uncertain payment, i.e. the marginal increase of utility becomes larger with the increase of the uncertain payment.

There are many different concepts of how to model utility functions incorporating risk, such as absolute risk aversion and its different shapes (constant absolute risk aversion, decreasing and increasing absolute risk aversion, etc.) and relative risk aversion and its shapes (constant relative risk aversion, decreasing increasing relative risk aversion, etc.). The model used in this paper follows, as previously mentioned, the concept of CRRA and its properties will be explained later in one of the following chapters.

2.1. Related Literature

A substantial amount of literature can be found when looking for articles which incorporate the CRRA function into their models in order to explain risk aversion. As already mentioned above the argument in utility functions can have a lot of different meanings. While some authors estimate the coefficient or risk aversion by comparing household consumption with demand for risky assets others try to estimate the coefficient by comparing demand for risky assets over demand for non-risky assets like T-Bills and the benefit a utility maximizing household can receive thereof. The basic idea behind the research is to compare one risky option with a safe option, the so called certainty equivalent.

Sydnor (forthcoming), for example, sets up a model for insurance deductibles, in which homeowners can choose between 4 different sets of insurance deductibles. The insurance plan with the highest deductible also has the lowest premium and vice versa. The author finds that 83% of all the homeowners in his sample chose a deductible which is lower than the maximum deductible of $1.000 but therefore also accept to pay a higher premium. Surprisingly, he finds coefficients of risk aversion to be significantly higher than 100 in order to explain the homeowners' decisions to pay high premiums which result in lower deductibles. This seems to be very unrealistic and does not coincide with any of the other literature on CRRA. The author himself states that his findings do not seem to be consistent with current literature and according to the values estimated in his model more than 99% of the homeowners would not participate in a lottery where they could loose $1.000 or win any amount of money they want.

Janecek (2004) included CRRA in his model and anaylzed the behaviour of individuals who gamble in a professional manner. He argues that the coefficient of relative risk aversion is much larger than what many other authors have so far estimated. Additionally, he argues that an individual’s behaviour towards investments is dependent on the individual’s wealth and not on anything else. His hypothesis is that the more people have been engaged in risk and risk taking, the lower their risk aversion will be and vice versa. He, too, finds high levels of risk aversion as proof of his argument. While they are not as high as Sydnor's estimates Janecek does find the coefficient of relative risk aversion to be higher than 40.

Only recently authors started to suggest that estimated values for the risk aversion will be in the double-digits. Earlier literature suggested the coefficient of relative risk aversion to be somewhere below, or around two, whereas recent literature estimates the coefficient to be above five. In general one can say that over the recent time higher values for relative risk aversion estimations have been found compared to earlier estimations.

One of the earlier works about CRRA has been done by Friend & Blume (1975). They were one of the first authors to employ a model with relative risk aversion as opposed to the utility functions which have been used by researchers until then. Before many believed risk aversion to be constant and absolute or decreasing and absolute. The authors study the wealth of households and their utility functions and then continue to look at market returns in order to estimate the market price for risk. According to their work they estimated the coefficient of relative risk aversion to be somewhere around two. They come to the conclusion that CRRA is a good approximation to describe the market.

Hansen & Singleton (1982) set up a model, in which an individual tries to maximize its utility. At first they explain how Euler equations can be used to explain stochastic processes within a model that uses expected utilities as the results in stochastic processes are never the same. They develop a model with CRRA as framework, in which an individual gains utility from consumption, and apply it to the stockmarket by looking at stockmarket returns data beginning from 1959 until 1978. Their results show that an individual will have a coefficient of risk aversion between 0,68 and 0,97.

Hansen & Singleton (1983), in their study the year after estimated the coefficient of relative risk aversion to lie between 0,26 and 2,7 (depending on small alterations in the model) by taking into account consumption as well as asset returns and the data they incorporated was on a monthly basis.

Another one of the earlier researches done by Mankiw (1985) tries to find out how sensitive consumption expenditure on durable goods as well as non-durable goods is with respect to changes in the interest rate. In the course of doing so the author also incorporates a CRRA function and finds coefficients of risk aversion for durable goods between 1,8 and 3,2 and coefficients between 2,4 and 5,3 for nondurable goods.

It is well known that the reciprocal of the coefficient of risk aversion is also called the intertemporal elasticity of substitution. The intertemporal elasticity of substitution tells us how weak or strong the first order condition of consumption, i.e. the growth rate, responds to a change in the real interest rate. This means that an individual which is very risk averse must also have a low coefficient of intertemporal substitution. Hall

(1988) tries to estimate a value for the intertemporal elasticity of substition in his research but the author mentions that in his research he does not want to make any statements about the coefficient of risk aversion as the two are disconnected in his opinion. The main topic of his research is that if the real interest rate is supposed rise the consumers will tend to delay their consumption. He argues that if the coefficient of intertemporal substitution is small it would present no problem with observations in reality but a low (or almost close to zero) value for the substitution would correspond to a very high (or close to infinity) coefficient of relative risk aversion and yet the individuals still seem to take “risky” decisisions which, according to the high coefficient of relative risk aversion, should not be possible. Additionally, he argues that Hansen & Singleton (1983) try to find an estimate for the coefficient of relative risk aversion but their model closely resembles that of Hall (1988) and therefore they are rather finding an estimate of the coefficient of intertemporal elasticity of substitution instead. However the author does not (and does not want to) provide any evidence for or against his argument as this is not the topic of his research. He simply states that others, who wish to see the coefficient of relative risk aversion as reciprocal of the intertemporal substitution should do so but he will not draw any conclusions from one to the other. Hall then analyzes the change in consumption over a period of time subject to the changes of price and comes to the conclusion that the value for intertemporal elasticity of substitution is close to 0,066 which would correspond to a coefficient of relative risk aversion of almost 15,2. Hall was one of the first to find such a high value for the coefficient of relative risk aversion but as already stated above he did not want to make any connection between the two coefficients. The research which has been mentioned up until now is rather older but it is still used as source in a lot of articles, even today albeit the fact that recent research tends to find higher levels of risk aversion.

Halek & Eisenhauer (2001) try to look at the demography of risk aversion. The authors want to find out what kind of demographic properties be it race, wealth, gender, religion, marital status, etc., influence the risk aversion. In order to do so they set up a model to estimate the coefficient of relative risk aversion by looking at life insurance data of around 2400 households and then they conduct a multivariate regression to see what demographic properties of their sample influences the degree of risk aversion. While it does not - for the purpose of this paper - make sense to go into detail about whether gender has an influence, or not, it is interesting to note that the degree of risk aversion for their households varies greatly. **Fig. 3** shows how the degree of risk aversion is mostly distributed across the sample which the two authors analyzed. The distribution of the coefficient of relative risk aversion is rather skewed and mostly around unity but it has a mean of 3,735. This high mean however comes as a result of a few extreme outliers with values of up to 680. Perhaps the median in this sample of 0,888 is a better way to sum up the graph and the analysis of risk aversion of the sample rather than the mean value of the coefficient.

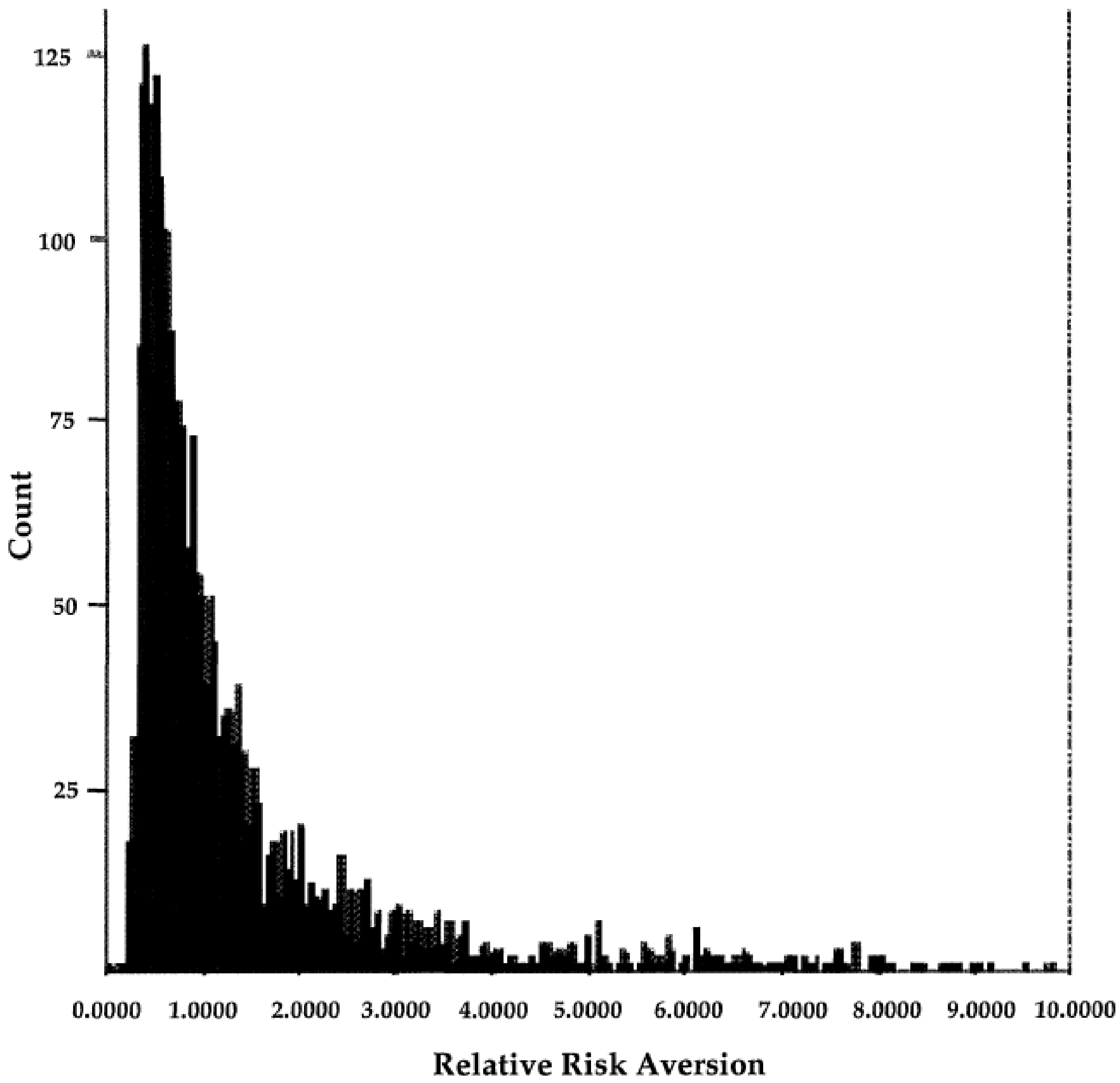

Figure 3: Distribution of relative risk aversion as by (Halek & Eisenhauer, 2001)

Gourinchas & Parker (2002) set up a different model analyzing different factors but - if one leaves out the outliers from the previous study – the value for the risk aversion they estimated are similar to the ones Halek & Eisenhauer (2001) found. Their goal is to estimate a coefficient of relative risk aversion by analyzing households and their consumption expenditure as well as their behaviour or pattern of accumulating assets over the lifetime. The way, in which households consume or accumulate assets is dependant on income uncertainty which in turn means that one can again measure a degree of risk aversion. It is interesting to note that Gourinchas & Parker chose to include, apart from the usual parameters, income growth into their model in order to show how consumer behavior (and therefore the risk aversion) can vary and change over time. Additionally, their model is supposed to account for precautionary and retirement saving which up until then seems to not have been done in previous research. Their estimations of the value of relative risk aversion lies between 0,5 and 1,4. The model set up in this paper will also incorporate income growth in order to reflect a situation which is closer to reality.

Many economists also estimated the risk aversion by looking at TV game shows or by conducting field experiments with gambles. The advantage obviously being that in this case it is possible to make real world observations and see how individuals react in certain situations. But it still remains questionable, whether or not risk aversion measured in game shows or gambles can be applied to normal everyday situations. Fullenkamp et al. (2003) provide such estimations by analyzing a popular American game show. They gathered information based on the TV game show Hoosier Millionaire by looking at all the participants who ever joined the game and by analyzing what steps they took during different stages of the game. The basic idea was to see when a player will choose the certainty equivalent and opt out of the game (players can continue the game or accept an offer presented to them by the game master) instead of continuing. They then set up a model incorporating CRRA and ran a Monte Carlo simulation in order to estimate the relative risk aversion. Their mean results for the coefficient range from 0,64 to 1,43. If they increased the the inital wealth level (by more than double) the mean results and the standard deviation of the coefficient increased only by a little bit. The research conducted by Fullenkamp et al. (2003) has, when compared to other research about gambling or TV game shows, a bit a larger sample but it still remains questionable whether or not the sample is large enough to be statistically representative.

Bombardini & Trebbi (forthcoming) analyze an Italian TV game show which has similar rules and similar procedures as the game show that Fullenkamp et al. have analyzed. Contestants can also choose to accept a monetary offer during the game and stop playing or continue to play. The results also seem to be quite similar: for a contestant with a labor income of € 18.000 per year the mean of the coefficient of rellative risk aversion is 0,53. In case they take the lifetime income as reference (here they assume that the income is an annuity from the lifetime income which was set at € 180.000) the results are higher, with a coefficient of relative risk aversion of 1,62. Depending on the different scenarios the outcomes of their research varies quite a lot, between 0,5 and 3 to be precise.

More recent research was conducted by Chetty (2006). His work is also based on estimating relative risk aversion but he does so by approaching it from another point of view. His main argument is the following:

> "Expected utility is the canonical theory of choice under uncertainty in economics. In the expected utility model, risk aversion arises solely from the curvature of the utility function, typically measured by the coefficient of relative risk aversion (γ). This paper shows that evidence on the effects of wage changes on labor supply imposes a tight upper bound on the curvature of utility over wealth (γ < 2). Hence, the standard expected utility model cannot generate high levels of risk aversion without contradicting established facts about labor supply."[2]

The author states that according to the expected utility model an individiual with a high degree of risk aversion will lower its supply of labor and instead increase its consumption of leisure if his wage is supposed to rise. However, this is contradictory

[2] (Chetty, 2006, p. 1)

to most of the research on labor supply and wage elasticity. It is well known that an increase in wage does not cause a strong decline in labor supplied by an individual. While this paper will not go into further detail here one example of research on labor supply and wage elasticity can be seen in McCurdy (1980). The marginal utility of consumption will not decrease strongly as long as the supply of labor and consumption are not complements. In order to set up the model the author had to find out in how far these to are complementary by estimating a value through empirical observation. The basic idea behind his research is to set up a model, in which the coefficient of relative risk aversion is explained by the ratio of the elasticity of income of the supply of labor to the elasticity of substitution of supply of labor, keeping in mind the value for the complements. The results for the coefficient of relative risk aversion range from 0,15 to 1,78 with a mean of 0,71.

Azar (2007) provides a pretty straightforward technique to estimate risk aversion. He tries to explain the equity risk premium in terms of risk aversion. By analyzing US stock markets he compares the concept of expected utility to the certainty equivalent because the point, at which an individual chooses the certainty equivalent will reveal the corresponding degree of risk aversion. The author does so by collecting data from the stock markets from 1926 to 1999 which is used in the framework of expected utility and compares it to the certainty equivalent. In this case the author defined the certainty equivalent as the rather short-term US T-bills. All this is done in the context of CRRA so that he can find an estimate for the coefficient of relative risk aversion. He then simulates for up to 7 different states of the economy but all of them have almost the same distribution of mean return and standard deviation. He concludes that the coefficient lies somewhere between 4,2 and 5,4 depending on which of the simulations with different amount of states the economy is in. Unfortunately the data collected only goes until 1999 and events like the Dot-com Bubble or the recent financial crisis have not been taken into account. If one was to include data from the past 10 years the value of relative risk aversion will most likely not be the same as in Azar's research. Although this piece of research has only been published recently many things have already changed. With the financial crises many countries find themselves in nowadays it remains questionable whether or not it already makes sense to include recent events to find an estimate, or to wait a few years until the global financial turmoil comes to a halt.

In almost every research which uses CRRA as framework in order to estimate risk aversion the authors choose CRRA by simply assuming this type of utility function. Chiappori & Paiella (2011) critisise this and the fact that every research done on relative risk aversion uses cross section data which only allows to see differences between subjects at one static point in time. Because of that it is not possible to present evidence that relative risk aversion is constant. In their paper the authors state that it is necessary to rely on panel data, data of subjects not only in one point of time but rather over longer periods of time in order to prove CRRA. They estimate the relative risk aversion by analyzing household income, wealth and the demand for risky assets. The authors find that there is a significant negative correlation between the wealth of individuals and their risk aversion, meaning the higher the wealth the lower the degree of risk aversion. But the change of the coefficent of relative risk aversion with rising wealth is so small that relative risk aversion is to be seen as constant. To be precise the authors find the correlation between the two to be -0,021. To prove their point they took the lower quartile with respect to wealth from their sample and analyzed, how the coefficient of relative risk aversion is distributed. The results of this can be seen in **Fig. 4**. They did the same thing for the highest quartile with respect to wealth as can be seen in **Fig. 5** and then they compared the two quartiles to each other. The lowest quartile is defined by a household having less than or equal to € 25.000 of financial wealth, whereas the highest quartile is defined by having a financial wealth of equal to or more than € 80.000. From looking at the two graphs one can see that risk aversion is distributed in the same way but the less wealthy analyzed in **Fig. 4** have a higher mean. Chiappori & Paiella find the overall mean risk aversion to be at around 4,2 but the risk aversion decreases to 2,5 if they leave the households whose fraction of risky assets in their financial wealth is smaller than 6% out of their analysis. The reason behind this being that the authors fear that transaction costs may play a more important role, if only a small part of a household's wealth consists of risky assets.

The estimations of relative risk aversion done in this paper are going to be consistent with most of the literature about CRRA.

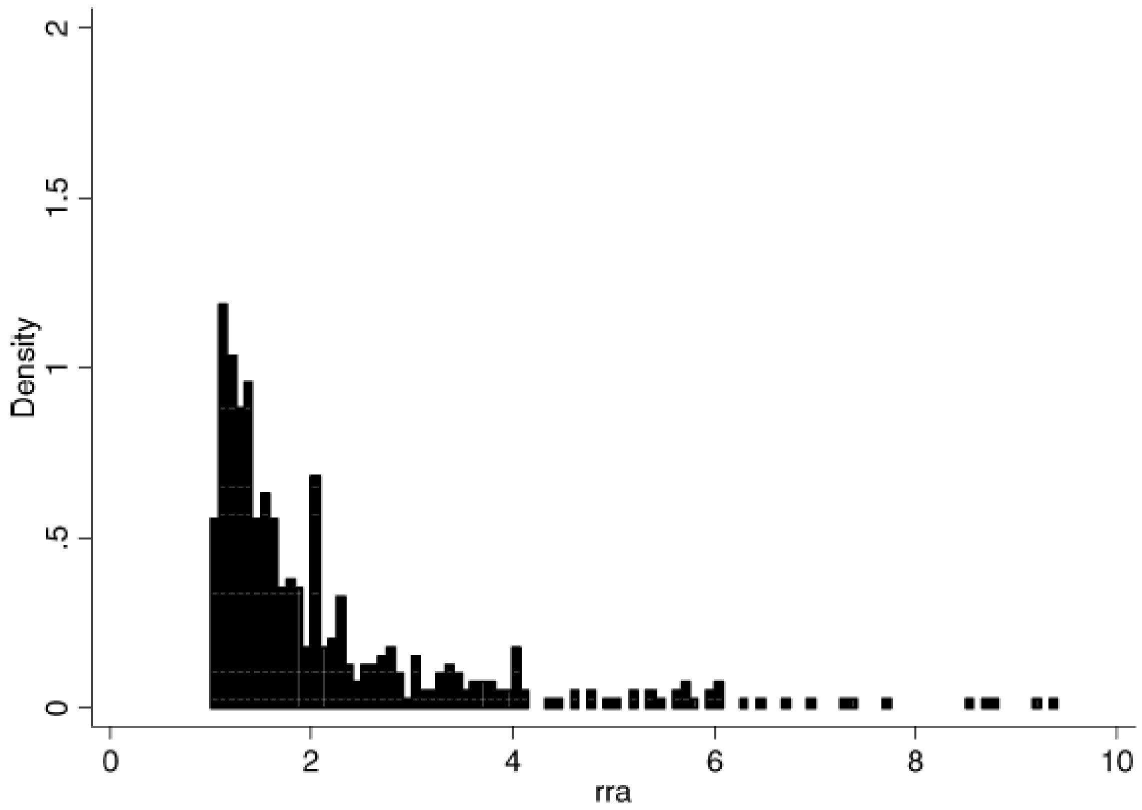

Figure 4: Lower quartile of wealth distribution as by (Chiappori & Paiella, 2011)

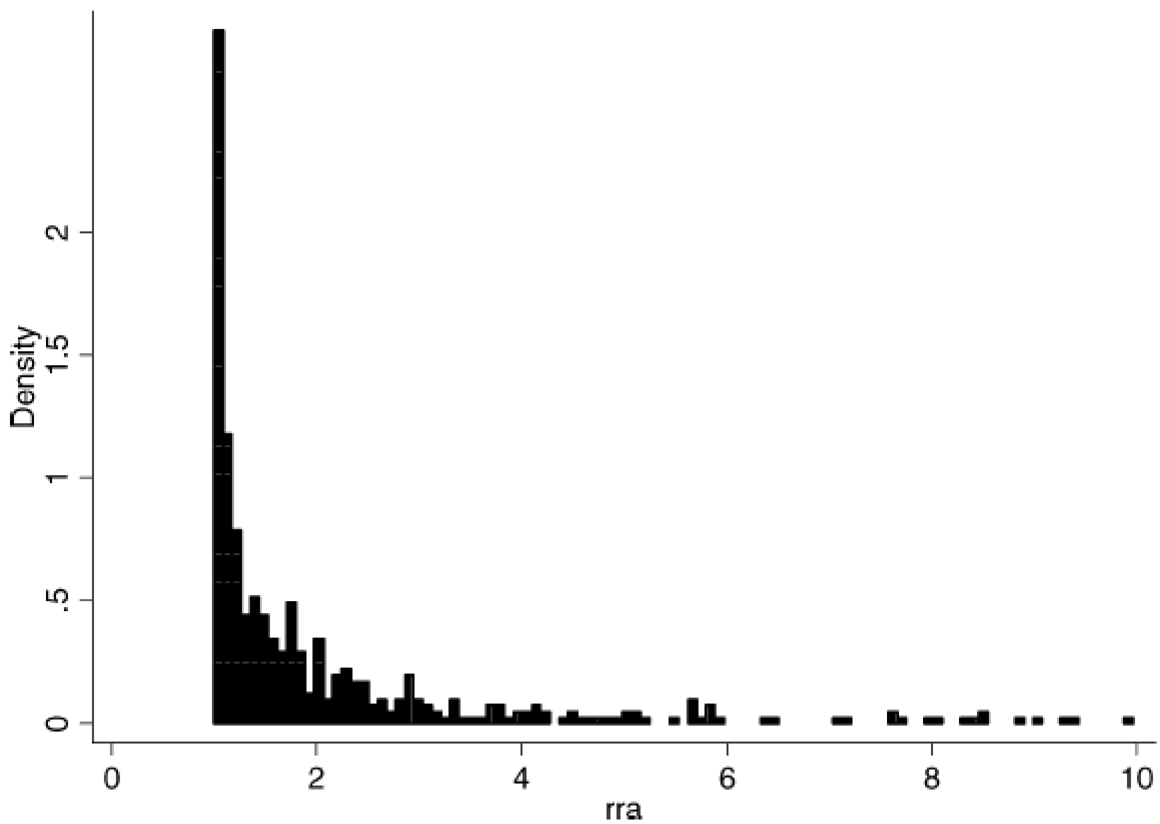

Figure 5: Upper quartile of wealth distribution as by (Chiappori & Paiella, 2011)

3. Mathematical Model

This chapter shall explain how the mathematical model, which is set up and employed here to estimate the coefficient of relative risk aversion, works. In chapter 3.1. it will be briefly explained what the concept of CRRA is as it will be the framework of the mathematical model.

Since the aim of the model is to calculate risk aversion under uncertain energy prices it will be explained in chapter 3.2. how the uncertainty will be dealt with, how the energy prices will be forecast and what the concept of a Brownian Motion is.

The last topic in this chapter will explain the general model, how the CRRA function and the Brownian Motion will be combined and what further aspects are being included.

3.1. CRRA

There are many economists who argue that there are other utility functions which are better in some aspects than CRRA but on the other hand there are many empirical studies which try to find levels of risk aversion by employing CRRA. While it is impossible to assign a utility function to a single individual many economists, such as Janecek (2004, p. 1, p.2), argue that the concept of CRRA can be applied to an aggregation of human beings because it seems to be the closest approximation to human behavior in total. The main reason behind this is that, as already mentioned above, human beings are by nature risk averse and additionally often weigh the downside of risk more than the upside of risk, i.e. the absolute value of a utility from losing € 100 in a lottery is greater than the absolute value of utility of winning € 100 in the lottery. Additionally, Chiappori & Paiella (2011) found evidence that relative risk aversion does really seem to be constant.

The CRRA function which is being used in this model is depicted in equation (1):

$$U(x) = \frac{x^{1-\rho}}{1-\rho} \tag{1}$$

The argument of the function, x, can be defined as consumption, or, as is the case in the model utilized in this paper as the income of the individual.

The coefficient of risk aversion, denoted ρ, is smaller than zero if the individual is risk affine, zero if the individual is risk neutral and larger than zero if the individual is risk averse.

If $\rho = 0$, as is the case for risk neutrality, one would get the linear utility function where marginal utility increases at the same rate as the marginal increase of payment.

If $0 < \rho < 1$ the function becomes the power function x^a with $0 < a < 1$. The limit of $U(x)$ becomes the $\log(x)$ as ρ moves towards one. Hence, if $\rho = 1$ the CRRA utility function turns into the normal $\log(x)$ function.

If $\rho > 1$ the function is concave, as when $0 < \rho < 1$, but the values of the utility function are negative with zero as the upper boundary, i.e. the higher the utility the closer the function approaches the value zero.

As the title of this paper already states and as already mentioned above it is assumed here that individuals are risk averse, hence the usage of the CRRA function and by its employment the degree of risk aversion shall be found, at which a human being will invest into a passive house instead of investing into a standard house. It can now already be said that the values for ρ in the different scenarios will be greater than one.

3.2. Energy Prices and Brownian Motion

The baseline for this model is to compare the utility an individual has from lower investment costs for the standard home but therefore accepting higher energy costs for higher heating requirement per year to the utility from higher investment costs for the passive house which in turn results in lower energy costs due to less heating requirement per year. It is obvious that the energy cost is dependent on the energy price and the price will not stay constant over time. The question arises how the price of energy shall be forecast in order to reflect a scenario which comes as close to reality as possible.

The first set of estimations by the model will be made using the gas price as a lot of homes in Austria use gas as energy carrier. The second set of estimations will be made using light heating oil as energy carrier. The only things which have to be changed in the model then are the price of energy as well as the consumption, whereas the rest in the model will remain unchanged.

Forecasting the energy prices will be done by employing a Brownian Motion. Brownian Motions are typically used to model stock market prices and the prices of commodities and therefore it seems sensible to use it here to forecast energy prices. A Brownian Motion, also referred to as a Wiener Process, is a stochastic process which is continuous in time. This type of random walk has to fulfill three properties. First of all it must be a Markov process which means that in order to produce a forecast for future values it is only necessary to know the current value. This is based on the principle that any public information on the commodity or stock price, which is to be forecast, is reflected directly and quickly in the current price. Second, the increments with which the price is going to change over any time interval have to be independent from each other and uncorrelated. Third, the increments by which the underlying asset or commodity will change in the Brownian Motion have to be normally distributed.

As there are different kinds of Brownian Motion to model and forecast assets and commodities it is important to pick one which seems reasonable for a realistic forecast of prices such as the gas or oil price. Different kinds of random walks include the basic Brownian Motion, the Brownian Motion with drift, the geometric Brownian Motion, and a Brownian Motion with a mean-reverting process. When implementing the basic Brownian Motion the change in price is mainly dependent on ε_t which is the random variable that follows a normal distribution with a mean of zero and a standard deviation of one. A geometric Brownian Motion with drift is a special case of a Brownian Motion with drift and it is often used to model or forecast economic or financial variables, such as interest rates, securities prices, and much more. In this research the Brownian Motion with drift was chosen to model the price change of gas and oil. It is assumed that the price of oil and gas will rise constantly by a certain factor and while the price may return to a lower level in the short run it is assumed that over the long run the price level of these two commodities will be higher. The key argument lies in the basic microeconomic principle of supply and demand that the two natural resources oil and gas are depletable and at some point more demand than supply will exist which will drive up the price. The Brownian Motion with drift employed in this model is shown in equation (2):

$$c_t^i = \alpha c_{t-1}^i + \varepsilon_t \sigma c_{t-1}^i \qquad (2)$$

$$\text{with} \quad i \ni \{p, s\}$$

$$t = 1, 2, \ldots, 40 = T$$

The variable c_t^i refers to the cost of energy as a result of heating requirement in period t (one period equals one year) and the superscript letter i refers to either the passive house or the standard house. In this equation $\varepsilon_t c_{t-1}^i$ is the uncorrelated incremental change of the Wiener Process and σ is the volatility of the commodity. ε_t is the random variable which has to be generated in a Monte Carlo simulation and has a mean of zero and a standard deviation of one. The variable α is the drift rate which shall have a value that reflects a real life scenario as closely as possible but it has to be mentioned that setting a drift rate over a time frame of 40 years is almost impossible.

One can argue that it would make more sense to use a Brownian Motion with a mean reverting process instead of a Brownian Motion with drift to model the prices of the different kinds of resource commodities. In a Brownian Motion with a mean reverting process the price of a resource commodity will fluctuate randomly in the short run but over in the long run it will return to a certain level again. It can also be argued that the value to which the price will return back to could be that of the level of marginal

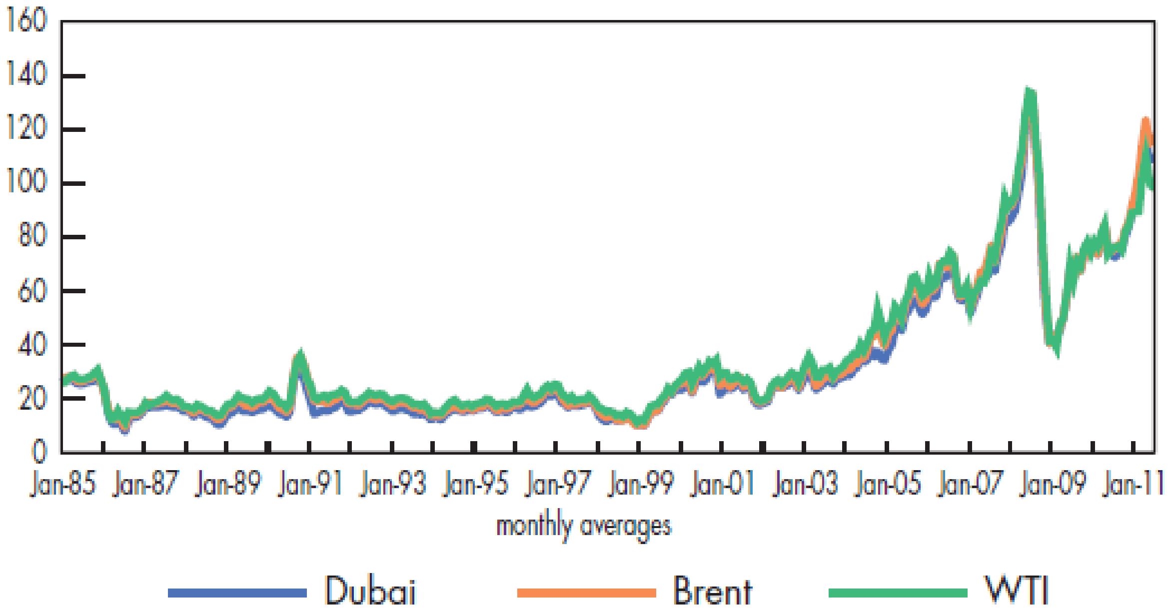

Figure 6: Key crude oil spot prices in USD/barrel as by (IEA, 2011)

production cost. While this seems a sensible argument it most likely will not hold when one looks at the price development of recent years. **Fig. 6** shows the development of the crude oil prices over the last 26 years. Here one can see that over the long run the price has not returned back to a certain level, such as the marginal cost of production. There are possibly two arguments why the oil price is not moving back to its marginal cost of production and which speak against using a Brownian Motion with a mean reverting process. The first argument is that the natural demand for oil is being affected by some sort of artificial demand. This means that a large part of the recent oil price increases came as a result of speculations at the crude oil market as it is a tradeable commodity. Oil is not only being bought because it is needed but because money can be made out of derivatives which use oil as an underlying. For this reason the oil price is being constantly manipulated and it is not possible for it to return to its marginal cost of production. Second, once the price of a resource like oil or gas rises high enough it becomes more and more feasible for oil and gas extracting companies to search for these resources in deeper regions as well as in regions where it is more difficult and more costly to draw out these resources. Oil platforms are getting bigger and more expensive and are able to extract oil from much greater depths nowadays. Once the price of oil rises enough to make it feasible to extract it at higher costs it is only a logical conclusion that this will raise the marginal cost of production. More and more companies within Europe are starting to evaluate projects to extract shale gas out of a deep regions. Extracting shale gas is very costly (the process of the extraction as well as from an environmental point of view) as it is more difficult to extract.

3.3. Explanation of the General Model and how the CRRA Function and Brownian Motion are combined

The next question is how to incorporate the two different costs of investment (passive house and standard house) into the model in order to show the different utilities from the two types of investment. If the full cost of investments were simply taken into account in the model as a one-time payment it would not be possible to calculate the coefficient of relative risk aversion as the two different utility curves would run parallel to each other. The periodic utility of the passive house investment would always be higher because the energy cost of heating requirement would always be lower than the cost of energy of the standard house. In that case it would always make sense to invest into a passive house and it would not be possible anymore to estimate a value for the coefficient of relative risk aversion. In order for the investment cost to have an actual impact on the utility function it will have to have an effect on the utility of every period. The logic behind this paper is that the passive house does cost more in the beginning than the standard house but when including risk aversion and energy price uncertainty (it is just assumed that energy prices will in general rise through the Brownian Motion with drift) it will make sense to invest in a passive house under the assumption of positive CRRA because the energy costs will be lower.

In order for the investment costs to have an influence on the utility of every period the investment costs will be treated as an annuity. An annuity in general is a constant flow of fixed payments for a specified amount of time. For example, when an individual takes up a loan, an annuity would refer to the total amount the individual had to pay back every period (dependent on the contract terms set out by the bank where the loan was made) for a given time frame in order to fully pay back the loan including the total interest. The annuity will be simply calculated as the annuity factor multiplied with the investment cost. This means that payments are usually constant and consist in one part of the debt retirement for the creditbase and to the other part of the interest rate payment as acquiring capital from a bank is costly.

Here, however, the individual will not be taking up a loan from a bank in order to finance the project so the question arises, how the investment cost can be looked at. In this case the investment costs will be treated as opportunity costs. That is to say that instead of investing into one of either projects the individual could put the money aside in a bank account and receive the yearly interest rate on its savings deposits. But as with the annuity for a loan, which has to be payed back periodically for a given timeframe in order to fully pay back the credit, the savings deposits can also be treated in the same manner. The annuity formula in this case will calculate the amount the individual can take out of his bank account (after having made the initial payment) for a given timeframe until its total savings including interest are depleted. Instead of investing into one of the projects the individual could put the money in a bank and take out a certain amount every year to use for whatever it wants.

Equation (3) shows how the argument x_t in the CRRA function is calculated

$$x_t = \hat{Y}_{t-1}(1 + r) - c_t - a_t \qquad (3)$$

The variable a_t in this equation refers to the annuity which comes as a result of investment. $\hat{Y}_t$ is defined as the individual's yearly income at period t and, as Gourinchas & Parker (2002) already have done in their research, the income will grow yearly by a percentage, r, which will remain constant but already has inflation taken into account. C_t is the cost at period t which is incurred from the heating requirement of the house. This variable will be simulated 5.000 times in a Monte Carlo simulation for every period in the model for a total of 195.000 simulations. The first period of the time frame is the starting point that is defined by the parameters and the fact that the costs incurred in the starting period are, by definition of the Markov Process, known.

When taking equation (2) and equation (3) and implementing them in equation (1) the following equation (4) can be obtained:

$$U(x_t) = \frac{[\hat{Y}_{t-1}(1+r) - (\alpha c_{t-1} + \varepsilon_t \sigma c_{t-1}) - a_t]^{1-\rho}}{1-\rho} \qquad (4)$$

This is the basic equation with which the utility of every period for every simulation will be calculated. One can also see here that previous period's utilities will not have any influence on the current utility.

The next problem is that all these different utilities cannot be compared to each other as they all occur in different periods of time. Because interest rates, the inflation rate, and own personal values will not be the same tomorrow as today earning the same amount of money today is not the same as earning that exact same amount of money in, for example, next year. When one has the option to invest into different projects and these projects go on over a longer period of time it is necessary to know what all the payments, which come as a result of the investment, are worth today. This concept is called the net present value concept and the next step will be to calculate the net present value for every simulation. Here it is important to find out how much the future utility which comes as a result of subtracting future energy cost and future annuities from future income is worth today. Therefore the utility of yearly income subtracted by the energy cost for heating requirement and the annuity from every period has to be added up and discounted. It is logical but important to note that this step has to be done for every simulation which will result in 5.000 different net present values. Equation (5) shows how the final net present value equation looks like, including the formula for the annuity:

$$NPV\big(U(x)\big) = \sum_{t=1}^{T=40} \frac{\left(\hat{Y}_{t-1}(1+r) - (\alpha c_{t-1} + \varepsilon_t \sigma c_{t-1}) - \frac{(1+b)^T b}{(1+b)^T - 1} I\right)^{1-\rho}}{1-\rho} (1+i)^{-t} \qquad (5)$$

In equation (5) the variable i represents the rate at which the future utilities will be discounted. Note that i in this model does not refer to any interst rate or inflation rate but rather it refers to the individual's personal "degree of impatience". The variable b refers to the credit interest rate.

As this model has 5.000 different paths it will be necessary to calculate an expected value of all the different outcomes. In a model which uses expected utility different outcomes are weighted by their chance of occurring and added up to give an expected value of all the options. Because this is a simulation where all the different outcomes are viewed as occurring with the same probability the net present values of all simulations will be added up and divided by the number of simulations to give the expected utility of the net present value. This can also be viewed as the mean net present value of the simulations.

Because the Brownian Motion which is utilized in this model does not follow a mean-reverting process but has a drift included the chances are higher that in some periods of the 195.000 simulations the cost of energy does exceed the income of the individual. This would result in extracting a negative root in the CRRA utility function. Since this is not possible that particular simulation will be left out of the expected value calculation and therefore the total number of "successful" simulations will be actually smaller than 5.000. In the basic scenario the total error count of the simulations for the utilities of the passive house investment is zero. For the simulations of the standard house investment the error count is 49 which when compared to the total amount of simulations does not require any particular action to be taken except to subtract these simulations from the total amount when calculating the expected net present value.

Once the expected net present value of the utility has been calculated for the passive house and for the standard house it is possible to depict the two utilities dependent on the degree of risk aversion in order to get two curves as a result.

Because the investment and therefore the annuity from the passive house is higher when compared to the annuity from the standard house the utility from investing in a passive house should be lower. But after a few periods the utility which results from investing in a passive house should be higher than the utility from investing in a standard house because although the annuity is higher as a result of $I^p > I^s$ the energy cost for the passive house, that is $\alpha c_{t-1}^p + \varepsilon_t \sigma c_{t-1}^p$, will be lower than the energy cost for the standard house, $\alpha c_{t-1}^s + \varepsilon_t \sigma c_{t-1}^s$. As a result of the lower energy costs required for the passive house the slope of the utility curve of the passive house is higher than the slope of the utility curve for the standard house. The point where the two curves intersect will give us the corresponding coefficient of relative risk aversion which an individual possesses in case it decides to invest in a passive house instead of investing in a standard house.

The mathematical solution is to set $E[NPV^p(U(x))] = E[NPV^s(U(x))]$ in order to find the point where both utility curves cross each other. This is shown in equation (6)

$$\frac{\sum_{n=1}^{N=5000} \sum_{t=1}^{T=40} \frac{\left(\hat{Y}_{t-1}(1+r) - \left(\alpha c_{t-1}^{p} + \sigma c_{t-1}^{p}\varepsilon_t\right) - \frac{(1+b)^T b}{(1+b)^T - 1} I^p\right)^{1-\rho}}{1-\rho}(1+i)^{-t}}{5000}$$

$$=$$

$$\frac{\sum_{n=1}^{N=5000} \sum_{t=1}^{T=40} \frac{\left(\hat{Y}_{t-1}(1+r) - (\alpha c_{t-1}^{s} + \sigma c_{t-1}^{s}\varepsilon_t) - \frac{(1+b)^T b}{(1+b)^T - 1} I^s\right)^{1-\rho}}{1-\rho}(1+i)^{-t}}{5000}$$

(6)

All the variables except for ρ are known which should make it possible to find the value for it when both expected net present values of the utilities are set equal to one another to calculate the coordinates of the point of intersection.

It is important to note that a risk neutral individual with $\rho = 0$ would not invest into a passive house as $\sum_{t=1}^{T=40} \frac{(\alpha c_{t-1}^{s} + \varepsilon_t \sigma c_{t-1}^{s}) - (\alpha c_{t-1}^{p} + \varepsilon_t \sigma c_{t-1}^{p})}{(1+i)^t} < \Delta I$. That is the net present value of the total energy savings (that is the difference between the cost of energy for the standard house and the cost of energy for the passive house) is smaller than the difference in investment cost ΔI between the two housing types. This is where risk aversion comes into play as the individual will accept taking a loss by investing into a passive house in order to offset the risk of the price volatility.

4. Parameters

Once the model has been set up the next task is to find the correct parameters which correspond to a real-world scenario. At first it is necessary to define the surface of the building that is to be constructed in the scenario. Most passive houses range from 120m² to 160m². For this model a surface area of 140m² was chosen which seems sensible as it is neither too big nor too small and should accommodate a household consisting of four people.

As for the passive house a heating requirement of 10 kWh/m²/year was chosen. This is exactly the limit at which a house still keeps the passive house standard and it was chosen because the heating requirement will on average be around these 10 kWh. When looking at Treberspurg et al. (2009, p.55) who conducted a post occupancy evaluation study 10 kWh/m²/year seems a reasonable value for this research. While an average heating requirement of around 128 kWh/m²/year was measured in Austria this value represents the average heating requirements for all households, according to Statistik Austria (2006). It still seems sensible to keep this report in mind as the heating requirement has most likely remained constant over the years. Nonetheless this value is distorted due to the inclusion of old and unrenovated apartment buildings and therefore this value is not deemed representative for newly constructed homes. As a result, the value for the heating requirement of newly constructed houses will be set at 75 kWh/m²/year. This value is a bit lower than the target value according to Austrian building regulations which is set at around 100 kWh/m²/year but it seems a sensible value as recently constructed homes already use better insulation materials and try to save more energy.

Concerning the consumption of light heating oil a precise value was a bit more difficult to find. Therefore it was assumed that a standard home in this scenario will consume about 14 liters [1] of light heating oil per squaremeter just for heating requirements. A passive house will only consume around two liters of light heating oil which should be close enough to correspond to a real life scenario.

For the prices of both energy carriers the annual average as determined by the latest report of Statistik Austria (2011) were chosen. These prices were measured over the year of 2010. The gas price will be set at € 0,06/kWh and the average price for light heating oil, which is reffered to as gasoil for households by Statistik Austria, was measured to be € 751,68/1000l. This is a little bit more than € 0,75 per liter. As these calculations are made for households it should also be mentioned that the gross price and not the net price has been chosen for the calculations in this paper.

Setting a drift rate for the two energy sources oil and gas for a time frame of 40 years is a rather difficult task. There are various factors which can have a drastic and prompt impact. The U.S. Energy Information Administration [2] provides a forecast for the residential natural gas as well as the distillate fuel oil price which depicts the price changes until the year 2035. According to the U.S. Energy Information Administration the gas price for natural gas as heating source is predicted to grow annually by only 0,5% and the distillate fuel oil price is predicted to grow 1,6% per year until 2035. In times like these this seems a rather conservative estimate. In this model both of the energy sources are set to move upward at a rate of 3% annually. This growth rate is quite high when compared to the U.S. Energy Information Administration but once again it has to be mentioned that the energy price is expected to move up as it can be expected that at least oil as natural resource will be depleted in the near future. Once the supply is not able to meet demand it is easy to show that these energy prices could rise even more drastically. Additionally, when choosing to construct or buy a new house the impact of energy consumption does play an important role in the decision process and therefore setting the drift rate a little bit higher should be a necessary thing to do.

As with the drift rate it is likewise difficult to forecast the volatility of both energy sources over the upcoming 40 years. In this scenario a volatility of 20% was chosen which should be enough to reflect a real-world scenario.

Additionally, it is important to note here that the discount rate which is used to discount the utility over time in order to calculate the net present value refers to “personal impatience”. The discount rate itself can be seen as the opportunity cost of capital. The value for the discount rate i will be set at 2% in the baseline scenario but since it is almost impossible to make a precise estimation of the discount rate since it refers to every human beings own subjective perception it will also be shown how the coefficient of risk aversion will change with respect to a change in the discount rate in a later sub-scenario.

It is also important to note here that the model can not be used in perpetuity with these parameters because the drift rate α is larger than the discount rate i. However, this shall not be of great importance since this model works with a timeframe of 40 years.

In order to take up a new loan with a duration of over five years a credit rate of 4,83% has been observed for the month of January 2012 whereas taking up a loan for the construction of a new home is a little bit less expensive according to the Austrian National Bank, ÖNB [3]. The credit rate for home construction has been valued at 3,03%. In the years between 2000 and 2010 the credit rate for a credit which is used to construct a new home was generally between 3,5% and 6%. The inflation has changed drastically over the past years as well. Statistik Austria (2012) reported the annual consumper price index which is a measure of inflation to be higher than 3% in the year after the financial crisis has started. In general, inflation between the years 2000 and 2010 has fluctuated between 1,5% and 3,2%. Only in 2009 inflation was at a low 0,5% whereas for the year 2011 inflation was measured to be at 3,3%. In this model it is assumed that the financial markets will become more stable over the time frame of this model and therefore the credit rate, denoted b, for taking up loans in order to build houses will become a bit lower. The credit rate was set at a value of 2% in order to calculate the annuities of both investments.

Concerning the income a yearly income of € 20.000 has been chosen. This value seems quite representative when one compares it to observations done by Statistik Austria (2011). The mean yearly income was measured to be at just a little bit more than € 20.000 and the mean increase in income from the year 2009 to 2010 was measured to be at 0,3%. As the low income increase from those two years might still be a delayed effect of the financial crisis it is assumed that the income increase, r, will be higher for the time frame of this model. Yet income increase will only be estimated to be a little higher, namely $r = 0{,}01$, the reason being to have a rather conservative estimate. While some sectors might enjoy a much higher increase others do not and therefore the mean increase will be held low in this model.

The last two parameters in the model are the cost of construction of a passive house and the cost of construction of a standard house. It is assumed that a standard house which shall also have a reduced amount of energy consumption for heating requirement will cost € 300.000 in this model. A passive house on the other hand will be more expensive. Time and experience have shown that a passive house nowadays will be somewhere between 5% and 15% more expensive [4] than its counterpart. The reason being that passive houses have a much better and therefore much more expensive thermal insulation and the building envelope has to be air-tight. Additionally, the room temperature in passive houses is always sought to be held constant. Therefore a much more advanced ventilation technology with a heat recovering system is necessary. For constant room temperature windows with triple heat-insulating glass have to be built in. In the case of this model the cost of construction of a passive house will be € 360.000 which is 20% more than what the standard house will cost. This value was chosen because it is often possible that additional special solutions are necessary when a passive house is being constructed.

5. Analysis

This chapter will cover the analysis of the model and show the outcome. After the model has been set up the first step which needs to be taken is to analyze the distribution of the random variable ε_t in the Monte Carlo simulation of the energy price change. When doing a Monte Carlo simulation for a Brownian Motion with a drift it is important that ε_t follows the inverse cumulative standard normal distribution with a mean of zero and a standard deviation of one. The random variable will be generated for a total of 195.000 times which comes as a result of doing 5.000 simulations for a period of 39 years as the costs in the first period are known. Then ε_t will be applied to the costs of heating requirement for both of the house types in order to replicate the same scenario under the same conditions for both. **Fig. 7** shows how the random variable ε_t is distributed. Here it can be seen that ε_t is distributed normally. The minimum is -4,16203 and the highest value lies at 4,376923. The standard deviation of the random variables is 0,99941 which should be more than close enough to one and the arithmetic mean is 0,003401.

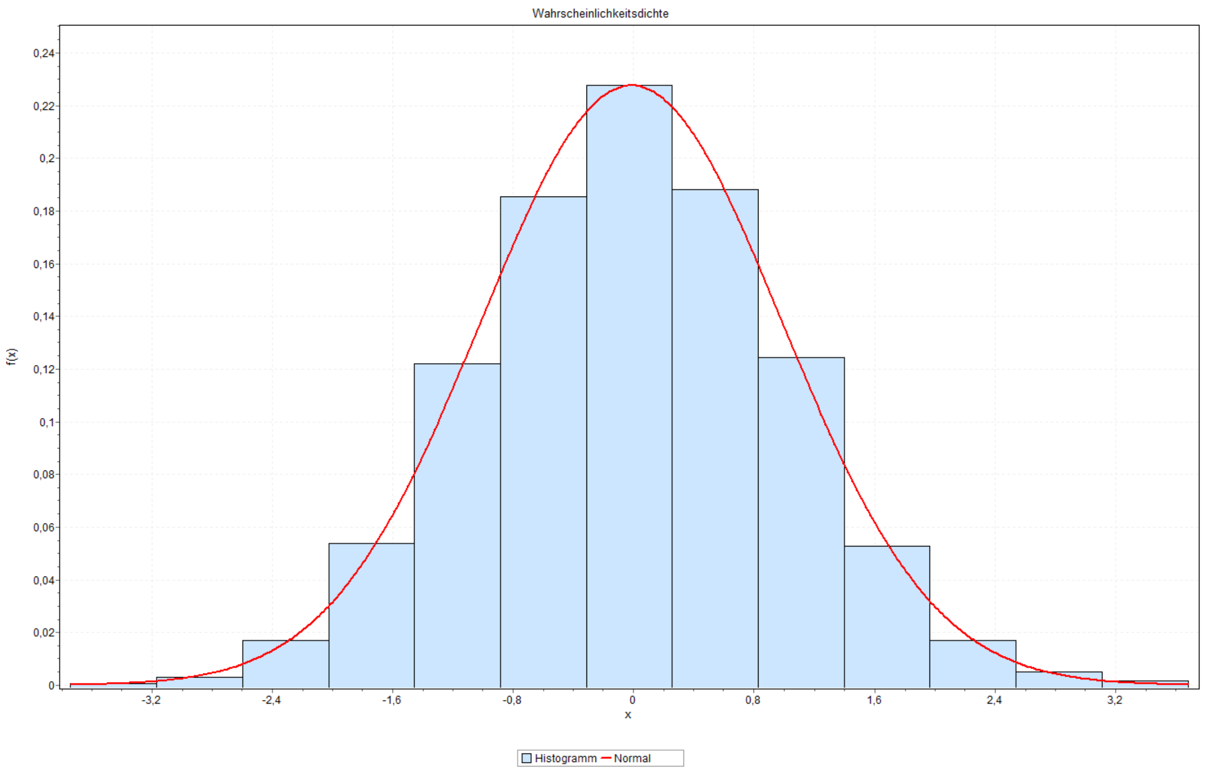

Figure 7: Distribution of the random variable ε

5.1.Analysis of the Relative Risk Aversion using Gas as Energy Carrier

When taking the random variables and relevant parameters and implementing them into equation (2) it is now possible to show the forecast of the energy price. Since the two parts in equation (2) are only multiplicative it does not matter if simply the gas price is simulated, or if the whole term c_t^i is simulated to receive the energy price forecastings. In this case c_1^i was calculated with € 0,06 to receive the cost of heating requirement in the first period and from then on c_t^i was forecast over the time frame as a whole. **Fig. 8** and **Fig. 9** both show how the forecasted heating requirement costs look like when being foracst through the Brownian Motion with a drift. The standard deviation for the random variable ε_t is, as mentioned above, almost one and the variance of the gas price was set at 20%. The samples one to four represent sample paths of the 5.000 simulations. Note that these sample paths as well as the rest can differ greatly. The trendline was calculated by leaving the variance of the gas price out of the equation and simply calculating the increase of the cost with the drift rate α. Some of the sample paths of the simulations deviate quite far from the trendline but in order to see if the simulation was done correctly it is simply possible to calculate the median from the 5.000 simulations and see if it follows closely around the trendline or not. In these two figures one can see that the sample paths one and two first are below the trendline but at around year 16 the second sample path moves above the trendline followed by the first sample path at around year 23. After they cross the trendline these two paths start to rise drastically and the cost of heating requirement for the first sample path exceeds € 550 in **Fig.8** and € 4.200 in **Fig. 9**. Note that both figures have the same price movement and look identical because the same ε_t was used in order to obtain the exact same conditions for both house types. A cost of heating requirement of € 4.200 does seem a lot but this is only one of the 5.000 simulations and does not at all mean that the possibility of such a high cost of heating requirement is high. The only thing where these two figures differ is in that they are scaled differently. This comes as a result of the fact that the cost of heating requirement for the passive house starts out at € 84 in the first period for all simulations whereas the cost of heating requirement for the standard house starts out at € 630 in the first period because of the higher energy consumption. When one only

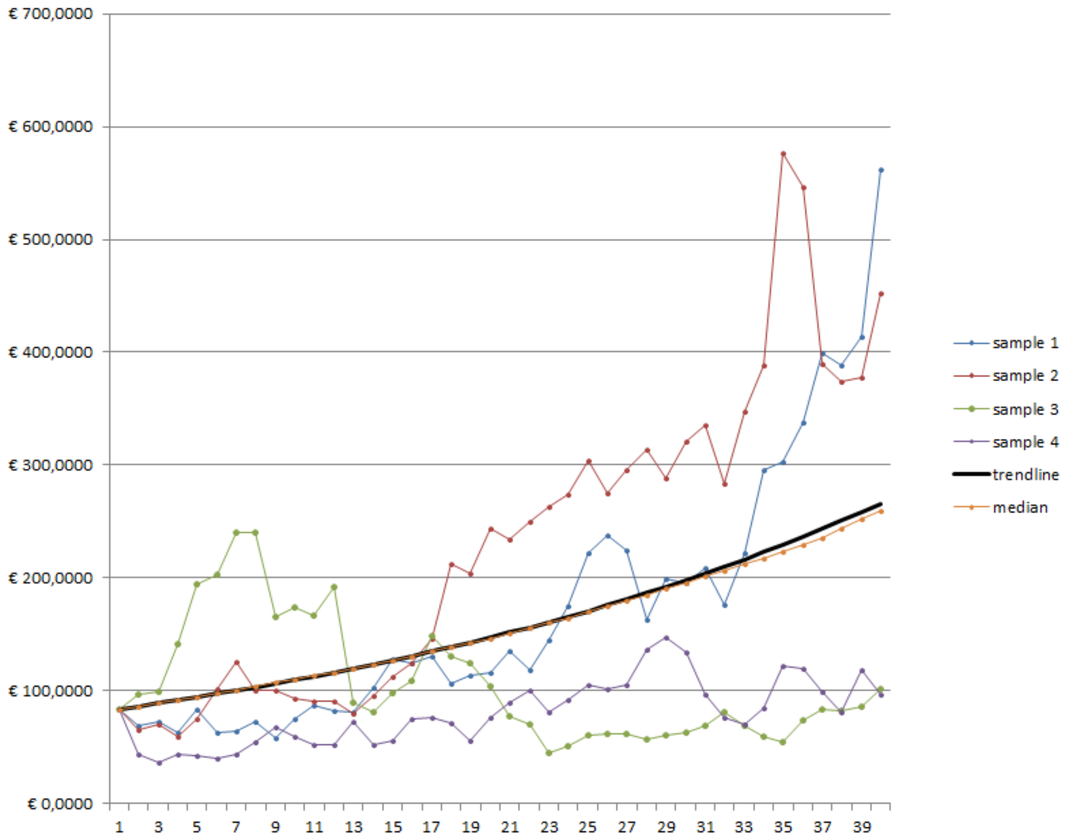

Figure 8: Forecast of the cost of heating requirement for the passive house with gas as energy carrier

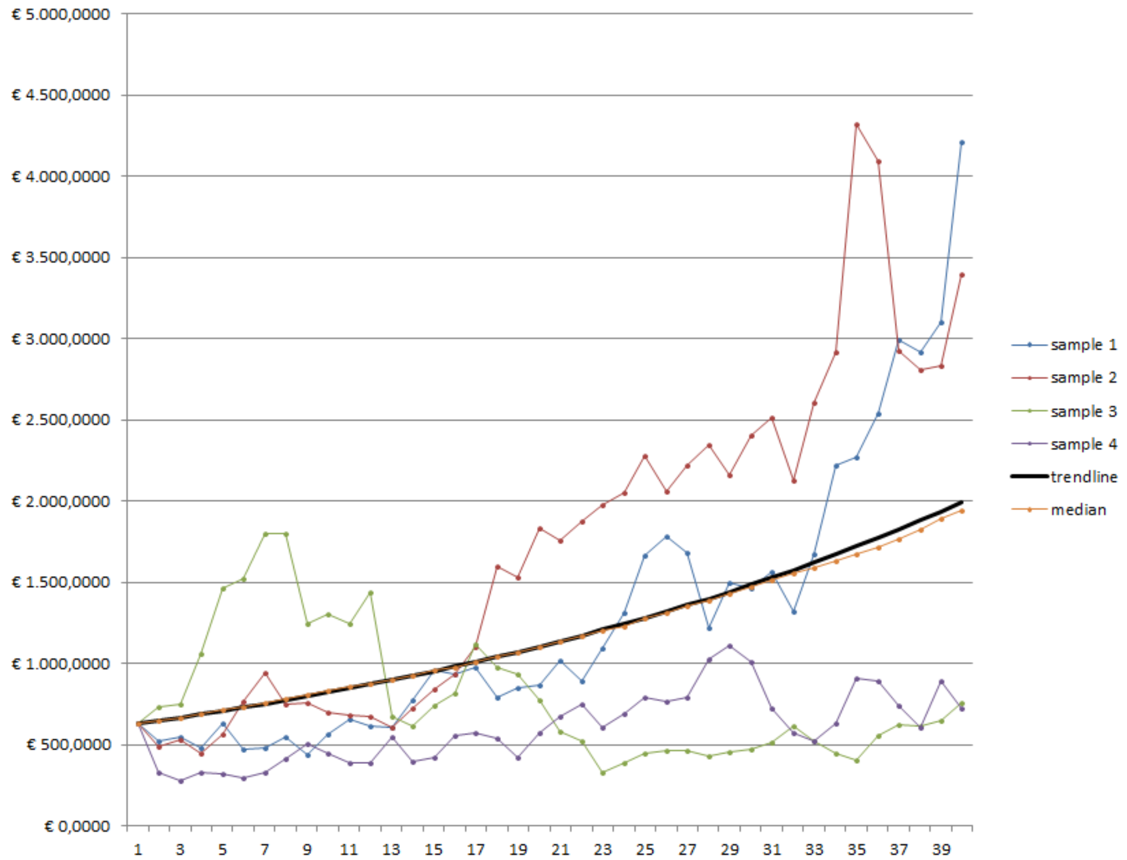

Figure 9: Forecast of the cost of heating requirement for the standard house with gas as energy carrier

looks at the trendline one can see that the cost in the first period for both energy carriers start out at the aforementioned values and the cost of heating requirement for the passive house will end at around € 260 after 40 years whereas the cost of heating requirement for the standard house will end at almost € 2.000. The important part is to test that the simulation has been conducted correctly. To one part this can be done by checking for the normal distribution of the random variable which has been done in **Fig.7** and to the other part by calculating the median of the 5.000 simulations. If all was done correctly the median of the simulations should be very close to, or be exactly the same as the trendline. In this case when the median is compared to the trendline one can see that they are almost identical except for the last 10 years where the median is a bit lower than the trendline but this shall not present a problem and the simulations can be further used to calculate the coefficient of relative risk aversion.

In order to calculate the utility of every period in every simulation it is now necessary to calculate the annuity factor and the annuity. With a credit rate of 2% and a time frame of 40 years an annuity factor of 0,036556 is obtained. If the passive house requires an investment of € 360.000 at the starting point the annuity will be € 13.160,07. The total value of the annuity will be € 526.402,8. It has to be kept in mind that this is not a credit which has to be paid back but that the total value of the annuity represents opportunity costs and this means that the individual opens up a savings account where it deposits the initial investment instead of using it for the house and thus receiving interest on the savings deposits. Every year the individual has the amount of the annuity at its disposal to use for whatever it wants for 40 years until the initial deposit including interest is used up completely. For the standard house the initial investment is € 300.000 which results in an annuity of € 10.966,72 for a total of € 438.669 over 40 years at its disposal.

Now the cost of heating requirement together with the annuity can be subtracted from the yearly income (subject to a yearly increase) in order to obtain the utilities of all periods and simulations. Then the net present value $NPV(U(x))$ as well as the expected net present value $E(NPV(U(x)))$ can be calculated. The two resulting utility curves should be concave and intersect at one single point which corresponds to the degree of relative risk aversion where an individual will decide to invest in a passive house and not in a standard house. If the individual were risk neutral, meaning $\rho = 0$, than it would never choose the option to invest in a passive house because with these parameters the cost of heating requirement c_t^p will be a lot smaller than c_t^s but the difference in the two does not exceed the difference of the annuities $a_t^p - a_t^s$. In the last period $c_t^s - c_t^p = € \, 1.686{,}33$, whereas $a_t^p - a_t^s = € \, 2.193{,}34$. This means that the difference in the annuities is too large and therefore the investment cost of the passive house is too high that it would make sense to invest for a rational human being. The total net present value of the difference in the cost of heating requirement (to put it in other words the total energy savings) is € 25.871,03 which is by far smaller than the difference of the investment cost ΔI which is € 60.000. Obviously, when one takes income into the equation and calculates the net present value of income subtracted by cost of heating requirement and the annuity to get $NPV(I^i) = \hat{Y}_t - c_t^i - a_t^i$ the difference becomes worse. To keep things plain it is assumed here too that the money which is left after the cost for heating requirement and the annuity have been subtracted will not be put in a savings deposit and will just be spent. In this case the net present value of the money which can be spent as a result from the passive house investment $NPV\,(I^p) = € \, 445.052{,}67$ is much smaller than the net present value of the money which can be spent as a result of the standard house investment $NPV\,(I^s) = € \, 492.018{,}31$. Equally one could assume that the money is saved but interest rate and inflation are the same and cancel each other out so that the saving's worth would not increase. In that case $NPV\,(I^p)$ and $NPV\,(I^s)$ could be looked at as being savings but their values would stay the same. As a result a risk neutral human being would never choose invest in a passive house. This example will only become interesting if one takes into account that human beings are risk averse and are willing to pay more as a result of trying to avoid or compensate for uncertainty over time. **Fig. 10** shows the coefficient of relative risk aversion which an investor will have when choosing to invest in a passive house under the assumption of CRRA. The y-axis represents the values of the utility functions of the two curves and the x-axis represents the value of the coefficient of relative risk aversion where the two curves will intersect. As per definition when the CRRA utility function is employed the values for the two utility functions are negative but the higher the utilities the closer the two curves converge to zero. The blue curve comes as a result from the investment in the house with passive house standard whereas the red curve comes as a result of the investment in a standard home. As discussed earlier one can see that the red and the blue curve both are concave but only have different slopes. From the graph one can also see that the slope from the blue curve is in general higher than the slope from the red curve which should be the result of the lower cost of heating requirement but the utility curve from the passive house investment has a lower starting point than the utility curve from the standard house investment. This should come as a result of the difference in investment costs.

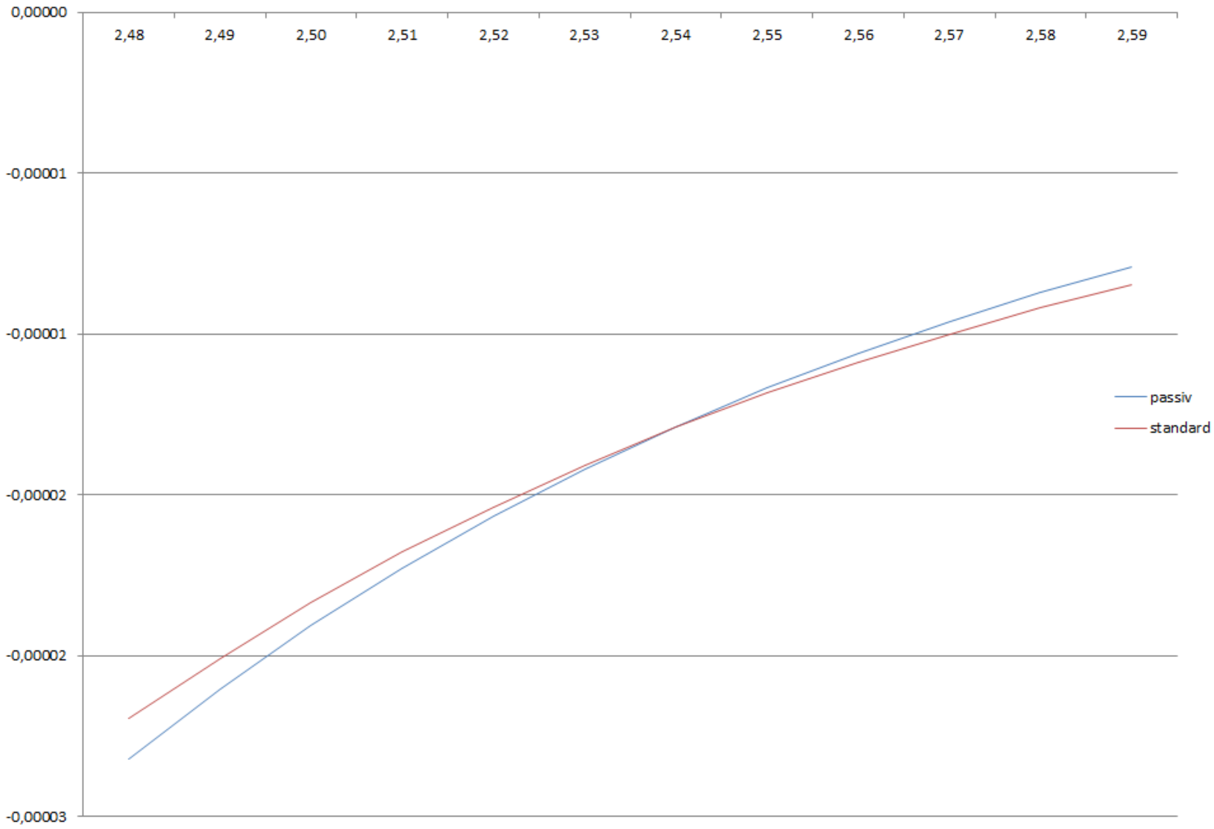

Figure 10: Comparison of the two utility functions and the corresponding coefficient of relative risk aversion with gas as energy carrier

At the intersection of the two utility functions the utility of the blue curve then becomes higher than the utility of the red curve which means that an individual in this particular scenario of investment will have a coefficient of relative risk aversion of close to 2,538 when it chooses to invest in a passive house and the volatility of the gas price is 0,2. A coefficient of relative risk aversion of 2,538 seems to be consistent with most of the findings of other authors in the related literature that was presented here.

5.1.1. Relationship between the Coefficient of Relative Risk Aversion and the Discount Rate

Because it is difficult to find a precise estimate for the discount rate as it refers to the individual's own impatience it seems only sensible to show how the coefficient of relative risk aversion changes when the discount rate changes. **Fig. 11** shows how the value of ρ changes when the discount rate i increases by one tenth every step. On the x-axis one can see i, the y-axis shows the corresponding value of the coefficient of relative risk aversion. The blue curve then shows the relationship between i and ρ. Note that this curve actually seems to be straight line and it tells us that the relationship between i and ρ is almost linear. In the baseline scenario $\rho = 2{,}538$ and this is also where the starting point of the blue line is in **Fig. 11**.

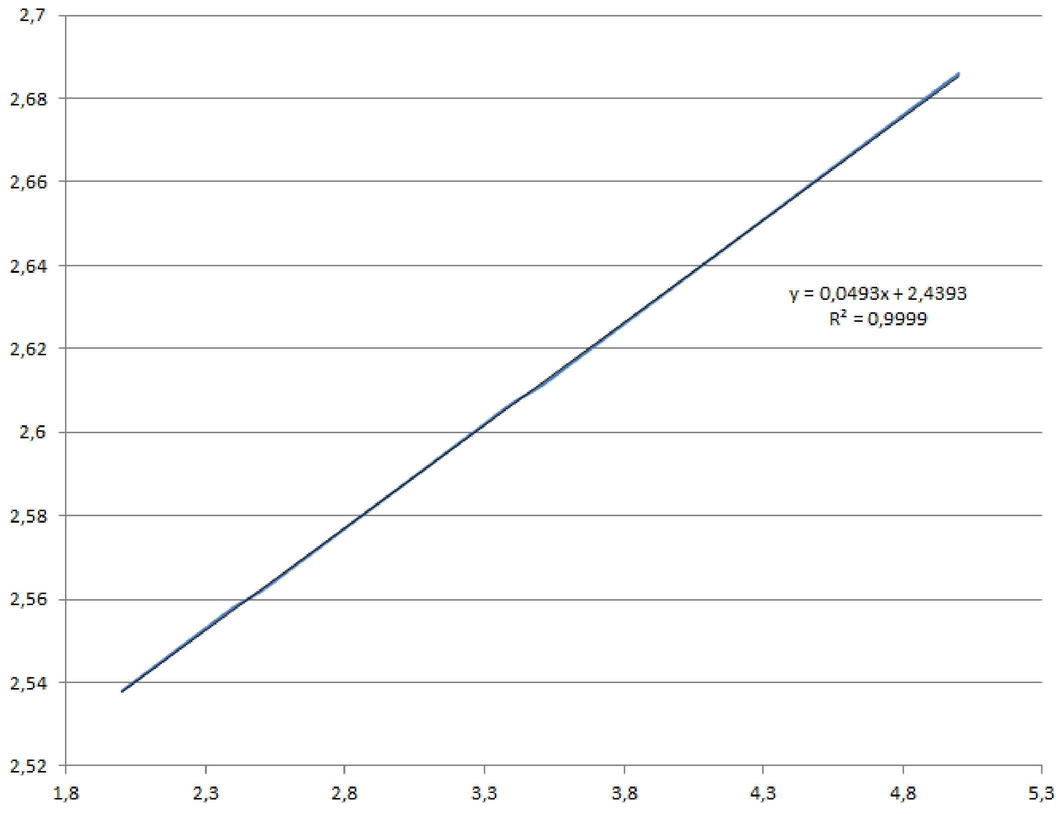

Figure 11: Dependence of ρ on the discount rate i with gas as energy carrier

Except for two points, one where $i = 0{,}025$ and the other one where $i = 0{,}035$ the incremental change is constant. In those two cases the incremental change is, compared to the other increments, only off by 0,001 and this could to be the result of rounding differences.

Apart from these two cases the incremental change is constant and for every 0,1% increase of i the value of ρ increases by 0,005 until the coefficient of risk aversion reaches 2,686 when the discount rate reaches 5%. This seems to show that the relationship between the increase in i by one tenth and the incremental increase of ρ can be defined by a linear function. Running the values, including the two with rounding differences, through a regression analysis delivers a linear function $y = 2{,}4393 + 0{,}0493x$ with $R^2 = 0{,}9999$. A high R^2 like this strongly supports the fact that the coefficient of relative risk aversion's dependency on the discount rate i can be explained by the aforementioned linear function. The trend line is barely visible here as it almost completely coincides with the curve. The basic findings in this sub-scenario show us that the higher the subjective discount rate of an individual the higher will be its risk aversion, too, when it decides to invest in to a passive house.

5.1.2. Influence of the Price of a Passive House on the Degree of Relative Risk Aversion

Experience from the many passive house constructions which are currently occurring all over Europe has taught us that in general passive houses are anywhere between 5% and 15% more expensive compared to standard houses. In the baseline scenario in which the standard house would cost € 300.000 this would mean that the passive house should cost anywhere between € 15.000 and € 45.000 more. Just to be on the safe side it was assumed here that the passive house would actually cost 20% more in case any larger alterations would have to be made to the area around the house (e.g. digging deeper underground for the installation of a geothermal heating unit) or simply because the prices of the resources for construction or labor costs increase. Although this assumption has been carefully made it does seem sensible to show how the degree of relative risk aversion is going to change as a result of different levels of investment costs for the passive house and how high the investment costs of a passive house can get until the coefficient of relative risk aversion rises towards infinity. In this sub-scenario the investment cost of the standard house is held constant at the previously mentioned € 300.000 whereas the investment costs of the passive house will start out at € 330.000 and will be increased in steps of € 10.000 until the level is reached where the coefficient of relative risk aversion will rise

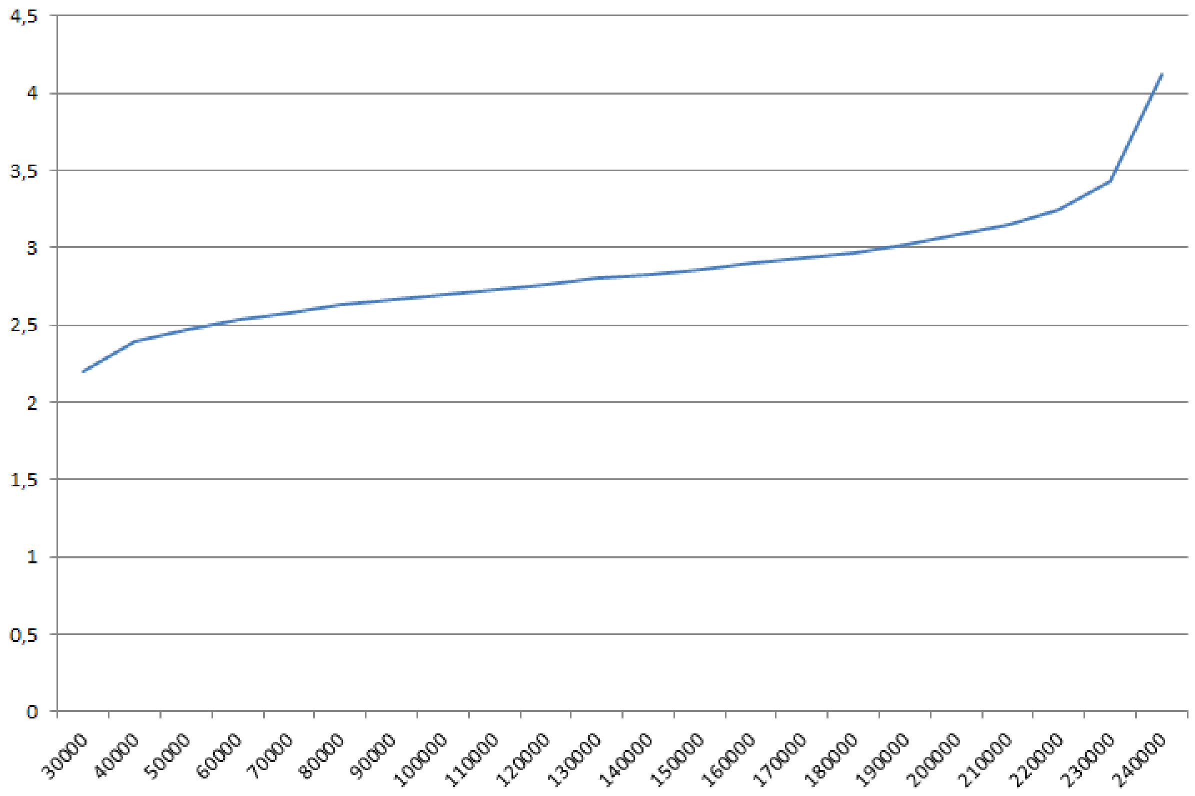

Figure 12: Coefficient of relative risk aversion, ρ, dependent on the change in investment costs for the passive house with gas as energy carrier

towards infinity. **Fig. 12** shows the result of how risk aversion is dependent on the increase of the investment costs for the passive house. On the x-axis of this figure one can see ΔI, that is the difference in investment costs between the two house types. On the y-axis one can again see ρ. If ΔI is less than € 30.000 the coefficient of relative risk aversion moves towards zero very quickly. To be more precise it was mentioned above that the net present value of the difference in cost of heating requirement, that is to say the benefit of energy savings from investing in a passive house is € 25.871,03. As ΔI comes closer to that value the risk aversion approaches zero and that would mean that the individual who is investing in a passive house is almost risk neutral. From that value on the increments of ρ rise very quickly until $\Delta I = € \, 60.000$. After that the second differential which means the increase of the increments of ρ flattens out and stays constant until $\Delta I = € \, 180.000$. Then the coefficient of relative risk aversion starts to rise sharply towards infinity. This would mean that an individual who would still invest in a passive house even it would cost more than € 540.000 and therefore € 240.000 more than the standard house should have an infinite coefficient of relative risk aversion. This seems to be quite obvious and logical as no one would consider investing in passive house technologies if the house would be that much more expensive when compared to the standard option unless the individual has such a high degree of risk aversion that it would be willing to pay more than € 540.000 in order to avoid the uncertainty of energy prices.

5.1.3. Influence of Monetary Incentives on the Degree of Relative Risk Aversion

So far the different sub-scenarios that have been analyzed all have one thing in common, namely that both investments would be completely financed by the individual which wants/has to invest in a new home. As it is necessary for mankind to reduce its ecological footprint in order to reduce the impact on global warming it is common in many countries that incentives are being provided by the government for people in order to help them to choose to construct a passive house rather than a cheaper standard house. The most common used and most basic form of monetary incentives which can be offered to future home owners is to provide them with a one-time payment in order ease the burden of the additional necessary investment. In Austria these one-time payments vary from state to state and can be anywhere between € 5.000 and € 15.000 [5]. For the purpose of this scenario it shall be shown how the coefficient of relative risk aversion changes in dependency on a change in monetary incentive. In **Fig. 13** one can see the relationship between the two. On the x-axis the value of the monetary incentive is depicted, on the x-axis one can see ρ again. The logic behind this graph is that the higher the monetary incentive is the lower the degree of relative risk aversion should be. If the government is to take away some of the cost of investment for the passive house it will be cheaper to build and thus the risk aversion will fall. The curve starts out at $\rho = 2{,}538$ which is the value of the baseline scenario where no monetary incentive is given by the government. What can be seen is that the value of the coefficient of relative risk aversion drops disproportionally compared to the increase of the monetary incentive. This means that the second differential of the curve becomes disproportionally smaller with constant increasing monetary incentive.

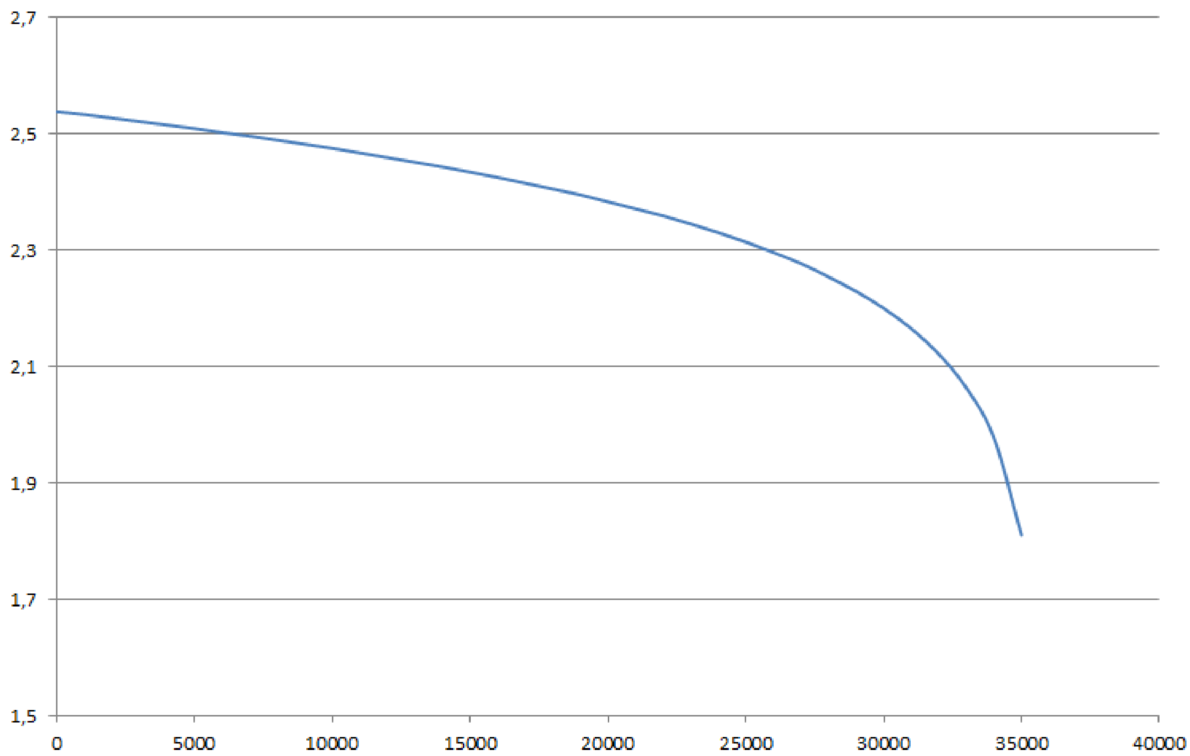

Figure 13: Coefficient of relative risk aversion in dependency on the height of monetary incentive with gas as energy carrier

5.2.Analysis of the Relative Risk Aversion using Light Heating Oil as Energy Carrier

The previous analysis was solely based on houses which utilize gas as the main energy carrier for heating requirement. This analysis would not reflect the current reality in Austria if it only utilized gas as the only carrier of energy and if it was assumed that all Austrian households would only rely on gas to heat their rooms.

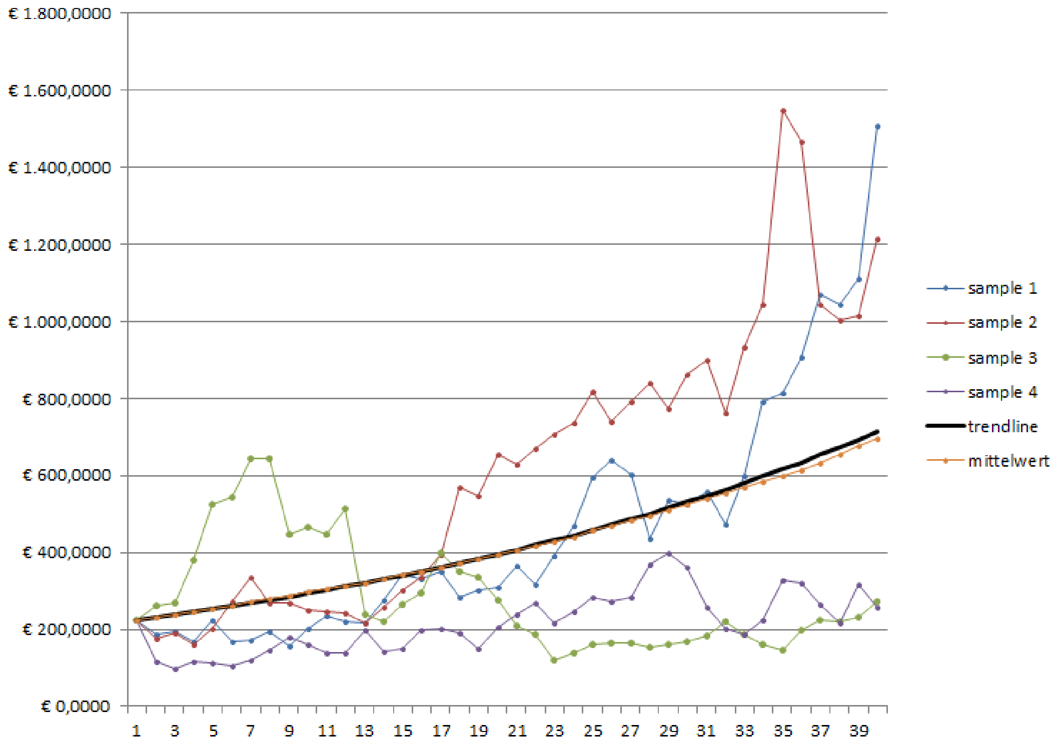

Figure 14: Forecast of the cost of heating requirement for the passive house with oil as energy carrier

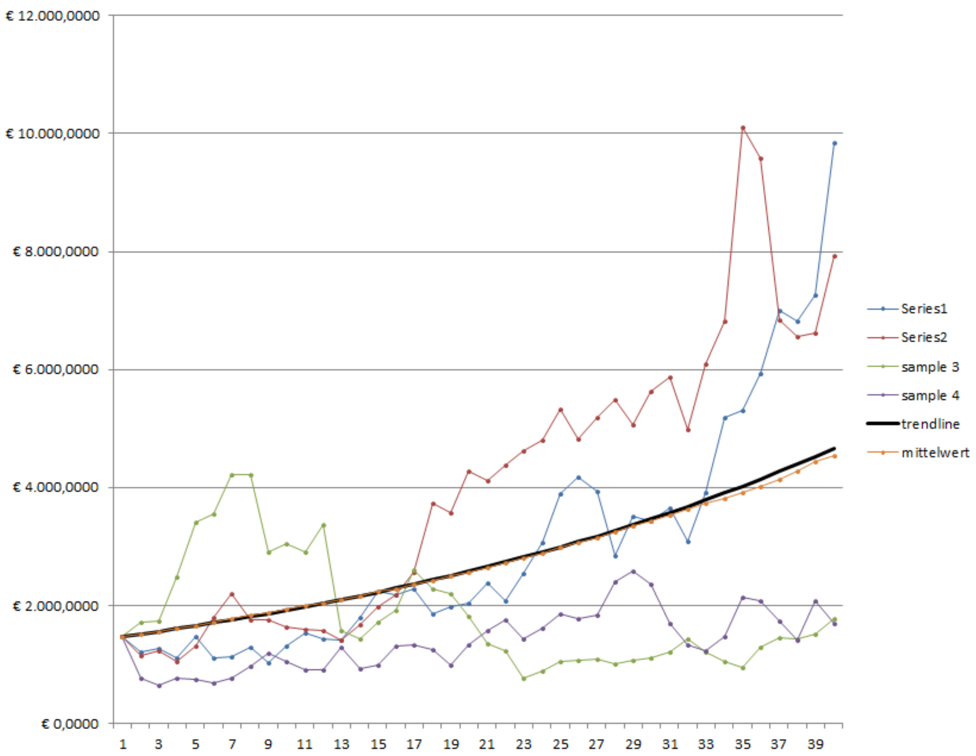

Figure 15: Forecast of the cost of heating requirement for the standard house with oil as energy carrier

Fig. 14 and **Fig. 15** both show the forecast for the price increase of oil and the cost of heating requirement resulting thereof. Note that these two simulations are exactly the same as they were before when the simulations where done utilizing natural gas as energy carrier but they are once again scaled differently. The same ε_t was used in order to produce the same conditions for this scenario because the results would otherwise not be comparable. Once again, $\sigma_o = 0{,}2$ has been chosen. Compared to **Fig. 8** where the cost of heating requirement utilizing gas for the passive house starts out at € 84 for 140m² and ends at around € 260 the cost of heating requirement now starts out at around € 225 and ends closely over € 700. One can easily see that using gas as energy carrier for heating is a lot cheaper than using light heating oil. Comparing the cost of heating requirement for the standard house in **Fig. 9** where gas is used and **Fig. 15** where light heating oil is used delivers the same results. Whereas the cost of heating requirement with gas as energy carrier started out at around € 630 they now start out at almost € 1.500. For gas as energy source the cost of heating requirement which has to be paid in the last period of the simulation is close to € 2.000 whereas when light oil is used as energy source almost € 4.700 have to be paid for the heating requirement.

If a risk neutral individual was to choose between a passive house and a standard house where both house types utilized a heating system that relied on light heating oil as energy carrier it would still not choose to invest in a passive house but only by a small margin. This time the difference in the cost of heating requirement, i.e. the energy cost savings, which come as a result from the passive house investment $c_t^s - c_t^p$ do surpass the difference in the annuity costs $a_t^p - a_t^s$ beginning from year 21. As a result the net present value of the energy savings is much higher but still slightly lower than ΔI. To be precise the net present value of the energy cost savings is € 59.123,77. When looking at the total savings, which accrue over time as a result of income subtracted by the cost of energy and the annuity, and discounting them to get the net present value $NPV(I^i) = \hat{Y}_t - c_t^i - a_t^i$ the results are quite similar. The net present value of total savings from the passive house investment lead to € 280.730,75 whereas the total savings from the standard house only add up to € 281.606,98. In this case a rational individual would still choose to invest in a standard house as the net present value of the total savings resulting from the standard house investment is still higher. Additionally, the net present value of the energy savings is not higher than the difference in investment cost. As the difference between ΔI and the net present value of the energy savings is much smaller now this should result in a somewhat lower coefficient of relative risk aversion when taking constant relative risk aversion into account again. **Fig. 16** shows the result and how high the coefficient of relative risk aversion must be when an individual chooses to invest into a passive house under the same, previous conditions. When comparing **Fig.16** to **Fig. 10** one can see that the increments of both utility curves in **Fig. 16** are larger as the scale on the y-axis is different compared to before. Nonetheless the increments of both utility functions when using light heating oil as energy carrier are more similar and therefore it is very difficult to see the point of intersection between the two utility curves as the two curves look almost identical. As stated above the coefficient of relative risk aversion is indeed smaller than it was before when using gas as energy carrier. To be precise $\rho = 2{,}181$ which is a bit more than 14% lower compared to the previous scenario.

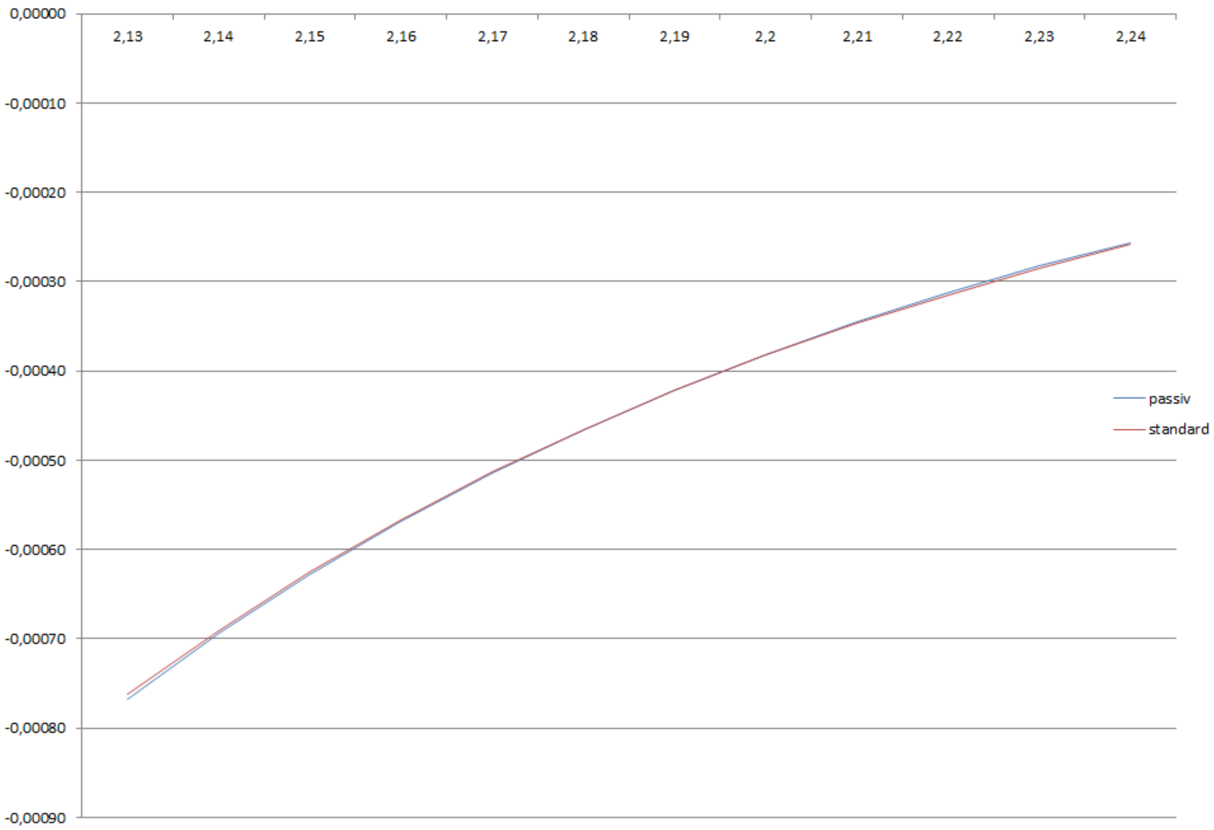

Figure 16: Comparison of the two utility functions and the corresponding coefficient of relative risk aversion with oil as energy carrier

5.2.1. Relationship between the Coefficient of Relative Risk Aversion and the Discount Rate

Next it shall be shown again how the interest rate influences the coefficient of relative risk aversion. **Fig. 17** shows how the risk aversion changes in correspondence to an increase in the discount rate. Unfortunately the curve seems somewhat unsteady but this should come as a result of rounding differences as it did before when the same

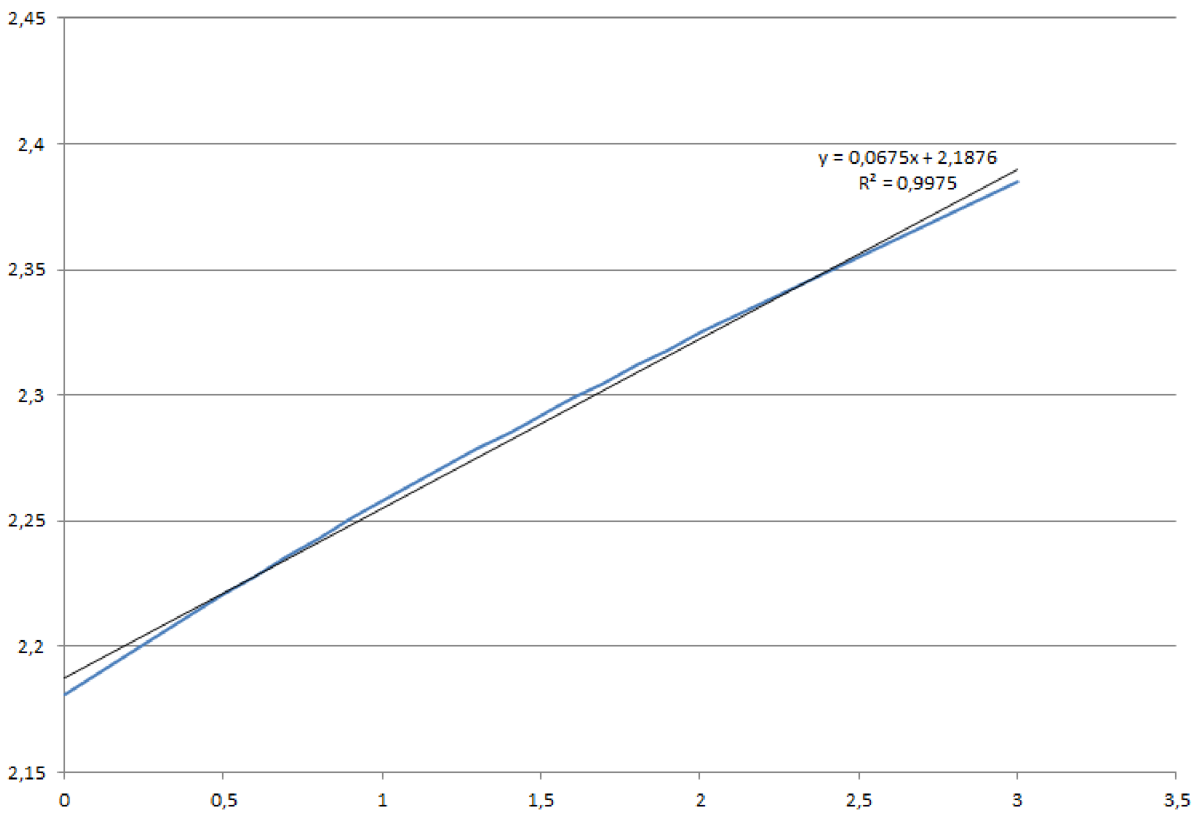

Figure 17: Dependence of ρ on the discount rate i with oil as energy carrier

graph was made using gas as energy carrier. Nonetheless this curve does seem to be concave but only very slightly. Increasing the discount rate i from 2% to 2,1% results in an increase of relative risk aversion, or $\Delta\rho$, by 0,008. When i is increased from 4,9% to 5%, $\Delta\rho$ is 0,006. This will probably not come as a result of rounding differences as the difference between the first $\Delta\rho$ and the last one seem "quite large" when one takes into account the minute differences which occur in all of the calculations of this paper. Altogether the increments in this graph are larger than the increments in **Fig. 11**. Therefore the range of ρ for $2\% \leq i \leq 5\%$ is also a little bit larger due to the higher increments for the specified area of the discount rate. Running the values through a regression analysis returns shows that the dependency of ρ on i can be explained by the equation $y = 2{,}1876 + 0{,}0675x$ with a significant $R^2 = 0{,}9975$. When the discount rate reaches 5% the coefficient of relative risk aversion reaches 2,385.

5.2.2. Influence of the Price of a Passive House on the Degree of Relative Risk Aversion

As has it has already been done in one of the previous chapters it is also important to find out how the price of the passive house will impact the degree of risk aversion. Because the difference of the net present values of energy savings is almost the same as ΔI, or to put it the other way because the total savings of both the passive house and the standard house are almost equal it is not possible to start out at € 330.000 as was done before in the scenario where both housing types were using gas as energy source. **Fig. 18** shows the results of how increasing costs for the

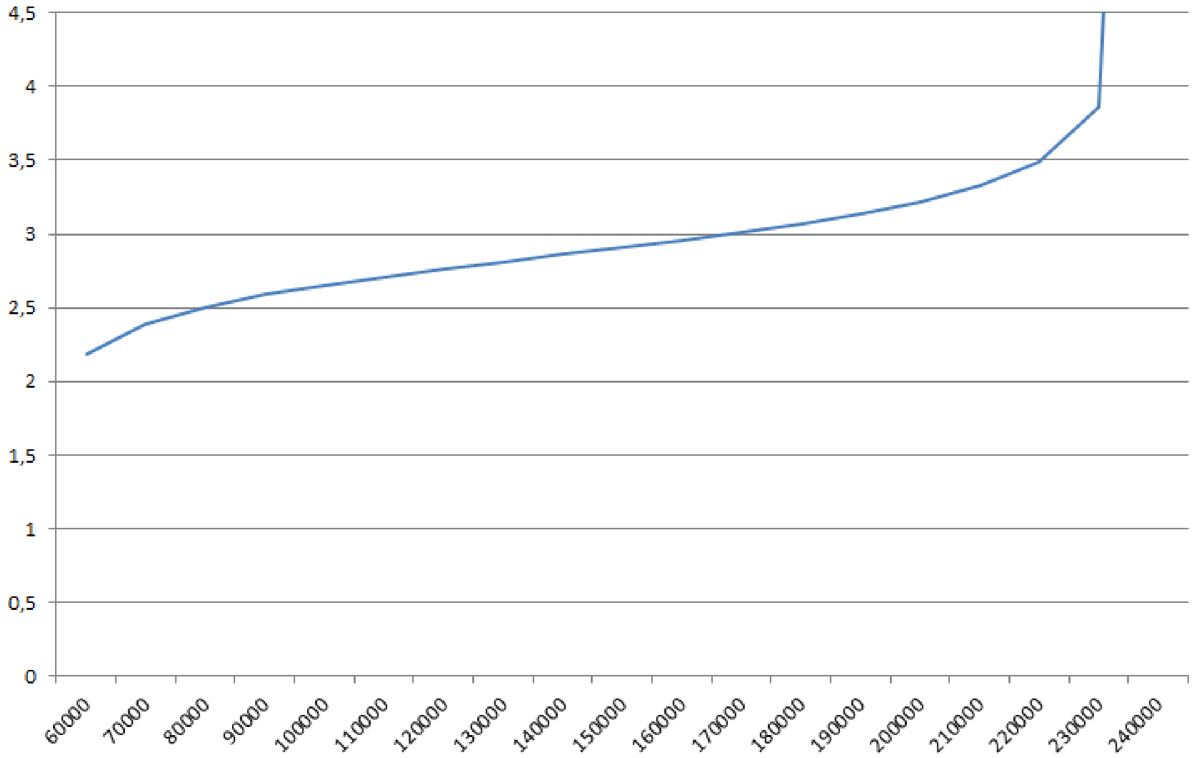

Figure 18: Coefficient of relative risk aversion, ρ, dependent on the change in investment costs for the passive house with oil as energy carrier

passive house affect relative risk aversion. The last point before relative risk aversion moves towards infinity was not included in the graph in order to show the resemblance to **Fig. 12**. It still has to be mentioned though that the last point where $\Delta I = € \, 240.000$ the coefficient of relative risk aversion is high compared to the other results, namely $\rho = 12{,}17$. Including this value would not show how similar the two graphs are to each other. If the passive house which used gas as energy source for its heating requirement would only cost € 330.000 the coefficient of relative risk aversion would be almost the same compared to when the house cost € 360.000 and oil is used as energy carrier for heating requirement. Until $\Delta I = € \, 500.000$ the coefficient of relative risk aversion in **Fig. 12** and in **Fig.18** seem quite similar although risk aversion is slightly higher when oil is used as energy carrier. At $\Delta I = € \, 500.000$ the risk aversion $\rho = 3{,}08$ when gas is used and when oil is used $\rho = 3{,}22$. The increments with which ρ increases when oil is used for heating requirement are only slightly higher compared to when gas is used. After that the increase of the increments in **Fig. 18** becomes much larger very quickly. Also, as was the case for the estimations with the utilization of gas, the coefficient of relative risk aversion's increments increase drastically shortly after $\Delta I = € \, 540.000$ and the value of ρ advances towards infinity in this figure.

5.2.3. Influence of Monetary Incentives on the Degree of Relative Risk Aversion

Since the net present value of the energy savings is almost as high as ΔI the scale in which the values move around in **Fig. 19** is very small compared to the range of values in **Fig. 13**. Altogether the risk aversion drops from 2,181 to 1,849 before no more monetary incentive is necessary to spur the interest in investing in a passive house. If a monetary incentive of more than € 6.000 was to be paid to the future owner of a house risk aversion would not be the reason anymore why an individual should not choose to invest in a passive house. The slope of this curve does decrease more with an increase of monetary incentive compared to when gas is used as energy carrier.

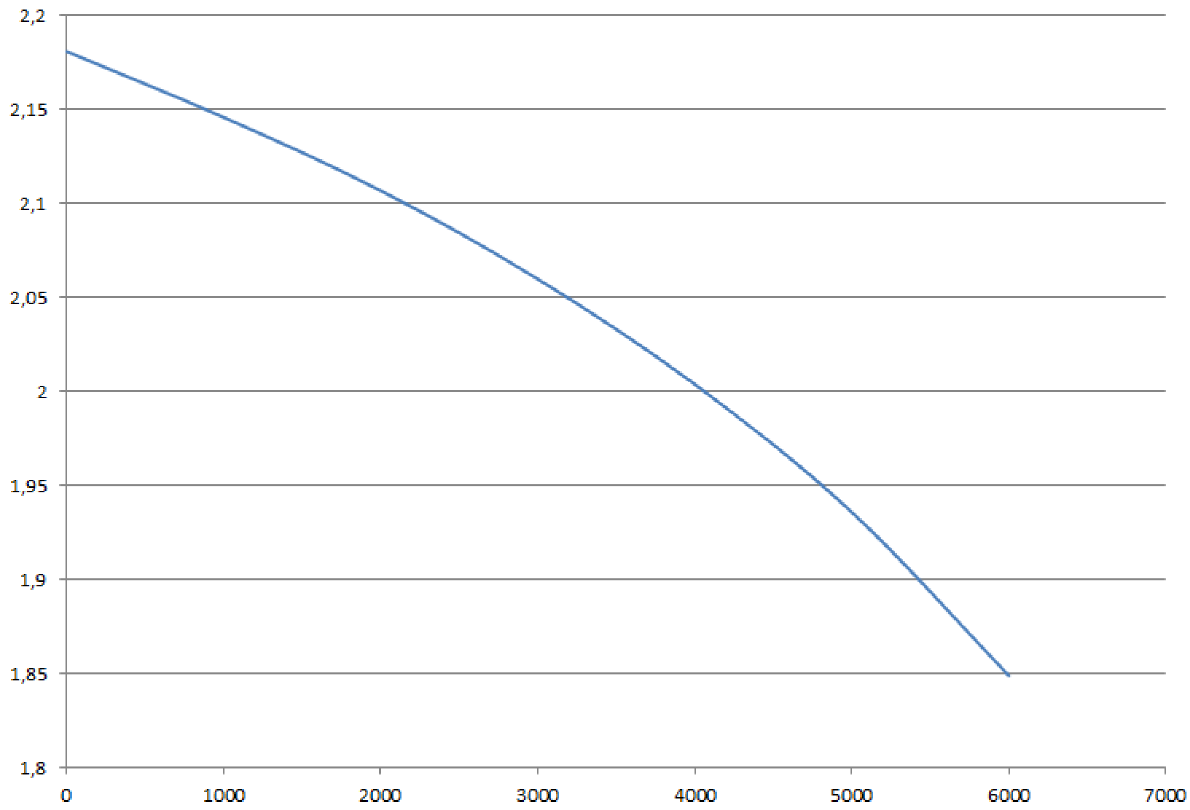

Figure 19: Coefficient of relative risk aversion in dependency on the height of monetary incentive with oil as energy carrier

5.3. Electric Energy for Heating Requirement and the Effect on Risk Aversion

So far oil and gas have been used to analyze the behavior of risk aversion using the CRRA function. According to a report done by Statistik Austria (2011) which measures the utilization of all energy carriers in households from the years 2003 to 2010 and further divides them into their purpose of use, i.e. space heating, water heating, and cooking, the energy carriers wood, oil and gas are by far the most used energy carriers for space heating in the year 2010. Out of the 16 listed possible energy carriers wood has the largest share of the total utilization. It has experienced a slight decrease of 1,1% in 2009/2010 compared to the year before and its share of the total is 25,6%. Following closely are the two already analyzed energy carriers natural gas with a share of 24,5% and light heating oil with a total share of 24,1%.

The method of heating a home which comes next in line is the utilization of district heating. Compared to the previously mentioned heating possibilities the share district heating of the total is even less than half of the share of oil, namely 11,6%. After district heating electric energy takes the next place with 4,4%. It is then followed by wood briquettes, heat pumps and solar heating energy. The fact that the share of electric energy is so little can be easily explained by the circumstance that it is quite an expensive method of heating one's own home. The average annual price of electrical energy for the year of 2010 as measured by Statistik Austria (2011) was € 0,19/kWh. Compared to the annual average price of gas in that same year this results in a difference of € 0,13/kWh. If a passive or standard house was to be heated solely by using electrical energy it would be so expensive that it would definetely make sense to invest in a passive house under that circumstance as even a risk neutral human being would invest into a passive house then. One only needs to recall that the cost of heating requirement with oil as energy carrier is € 225,504 and look at the net present value of the energy savings where it was almost equal to ΔI. In the case when electrical energy is used to heat the home the year one cost of heating requirement already starts out at € 266 for the passive house. It has to be mentioned that the parameters which are being used are the same one as in the baseline scenario, meaning that the passive house will require 10 kWh/m² and the standard home will require 75 kWh/m². This will evidently result in even higher costs of heating requirement for the standard house and therefore the net present value of energy savings will be higher, too. To be precise the net present value of energy savings will be € 81,924,92 which is higher than ΔI. As a result also risk neutral individuals will invest into a passive house should they be using electric energy for space heating. Therefore, it is not necessary anymore to calculate the degree of risk aversion using CRRA in this case.

5.4. Influence of Creditworthiness on Annuity

This chapter will deal with the annuity and the creditworthiness concerning the cost of capital. It is well known how the annuity is calculated. In this case the annuity looks like the following:

$$a^i = AF^i * I^i$$

The annuity factor AF^i is calculated on a basis of 40 years and with a credit interest rate of 2%. The superscript letter i refers to either the passive house or the standard house calculations. Basically the two annuities look like the following equations:

$$a^s = AF * I^s$$

$$a^p = AF * I^p$$

In the case where the credit interest rate $b^s = b^p$ which means that the credit interest rate is the same for both the passive house and the standard house one can further say that

$$\Delta a = AF * (I^p - I^s)$$

In the aforementioned formula $I^p - I^s$ equals € 60.000 in the baseline scenario. Yet if $b^s > b^i$ because the incentive for building a passive house set out by the government might come in the form of being able to acquire a cheaper credit instead of in the form of a direct one-time payment or as a result of a different creditworthiness the annuity factors will be different. In case $b^s > b^i$ the difference in the annuity will be smaller than before

$$\Delta a < AF * (I^p - I^s)$$

In this case the annuity factor has to be split up and the equation will look the following way

$$\Delta a = AF^p * I^p - AF^s * I^s$$

Fig. 20 shows how the difference between the two annuities is dependent on the difference of the annuity factors and therefore on the difference of the values of the cost of taking up a credit. The credit rate for the passive house is fixed at 2% whereas the credit rate for the standard house varies between 1% and 10%. The annuity of the passive house is in general higher as a result of the higher investment cost required for it. In the baseline scenario where both the credit rates are fixed at 2% the difference between the two annuities $\Delta a = € \, 2193{,}345$. This result can also be seen in **Fig. 20**. The slope of this curve is negative in general but since it is not at a 45° angle a change in the interest rate for the credit of the standard house does not correspond one to one with a change in Δa. After a close look one can see that the slope is not constant, it is concave and therefore the slope is slightly decreasing with a higher interest rate. Because the annuity of the passive house is higher than that of the standard house the credit rate of the standard house will have to be higher until the annuity of the passive house becomes cheaper than that of the standard house. Between a credit rate of 3% and 4% for the standard house the annuity of the standard house will be higher and the line in the graph crosses the x-axis. As a result the values will turn negative.

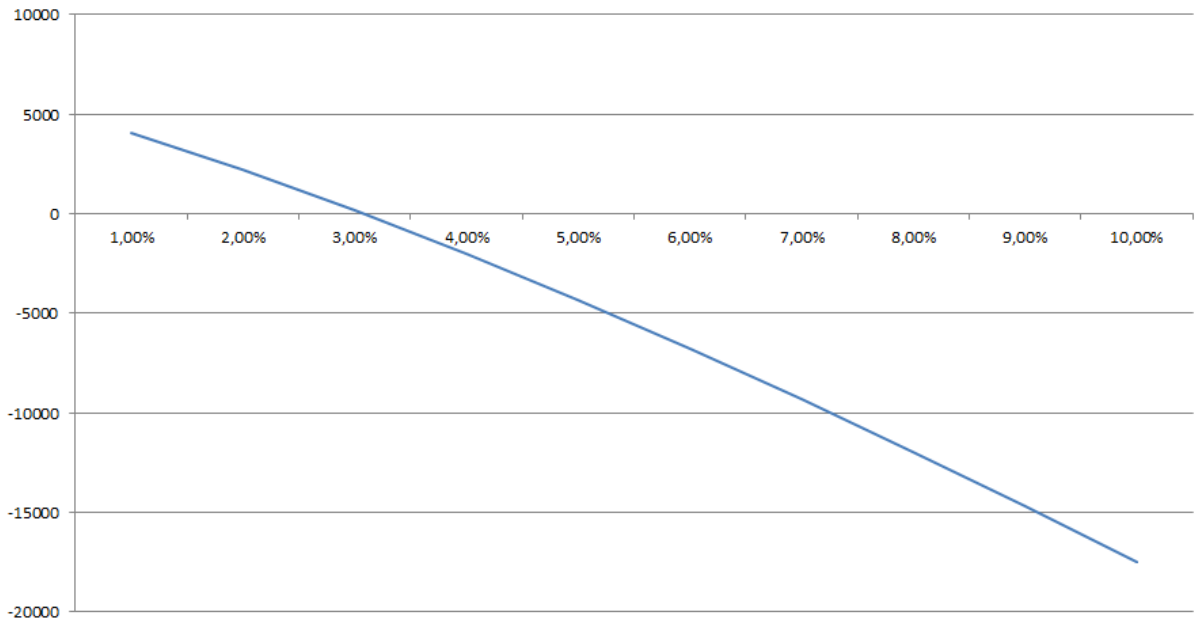

Figure 20: Comparison of the two annuities with respect to different credit rates

6. Conclusion

The goal of this paper is to analyze how high the coefficient of risk aversion will be by implementing the CRRA utility function and comparing two different utilities resulting from an investment into a standard house and an investment into a passive house under uncertainty of energy prices. This was done by calculating the utilities over 40 years which result from the investment into one of either housing standards. The cost of heating requirement which includes the energy price was forecast using a Brownian Motion with a drift and simulated 5.000 times. The utilities were calculated by analyzing the savings of an individual. The savings themselves were calculated by taking into account the income of an individual including a yearly increase which was then subtracted by the cost of energy for heating requirement as well as the investment which was converted into an annuity in order to be able to include it in the utility function. The assumption which was made here was that the savings from the preceding period will not have an affect on the utility of the following period. After having done this both utility functions were compared to each other. The point of intersection at which the utility functions will cross reveals the coefficient of relative risk aversion which an individual has when it decides to invest into a passive house under previously determined conditions. This has been done for different energy carriers in a baseline scenario and it was also shown in sub-scenarios how the coefficient of relative risk aversion will change in dependence of varying parameters.

The resulting coefficient of relative risk aversion in the baseline scenario varies between 2,181 and 2,538 depending on the energy carrier which is used for heating requirement and furthermore the coefficient of relative risk aversion varies between 1,849 and 12,71 depending on what sub-scenario is analyzed.

These results seem to be in line with most of the findings which have been presented by other authors. However, it would be possible to make different assumptions and include much more variables. Further interesting research on this topic could be done by including consumption and the behaviour thereof by analyzing the savings which accrue over time as a result of investment and their impact on following periods as well as including income uncertainty. Both of these factors would most likely have an impact on the decision whether or not an investment like this should be done since this type of investment is not a regular investment which an individual does on a day to day basis and it has a large impact on the household.

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Appendices

Appendix A: Abstract – German

Ziel dieser Arbeit ist es einen Wert für die Risikoarversion zu finden, der ein Individuum veranlasst unter unsicheren zukünftigen Energiepreisen in ein Passivhaus anstelle eines normalen Hauses zu investieren. In diesem Szenario wird die Annahme getroffen, dass das Individuum die Wahl hat in eines von zwei Häusern mit unterschiedlichen Standards zu investieren. Die Standards wurden laut dem „Energieausweis für Gebäude", welcher in der OIB Richtlinie 6 rechtlich verankert ist, festgesetzt. Zusätzlich wurde noch die Annahme getroffen, dass diese Investition nicht auf einen späteren Zeitpunkt verschoben werden kann, sondern sofort getätigt werden muss. Der Zeitrahmen in diesem Modell wurde auf 40 Jahre festgesetzt.

Die Energiepreise werden durch eine Monte Carlo Simulation ermittelt. Um die Simulationen durchführen zu können wurde eine Brownian Motion mit Drift gewählt. Des weiteren wurde angenommen, dass die Nutzenfunktion des Individuums die Eigenschaften der konstanten relativen Risikoaversion besitzt.

Die Risikoaversion wurde anhand mehrerer realitätsnaher Parameter berechnet. Beispiele hierfür wären die Drift Rate der Brownian Motion, die Volatilität der Energiepreise, die jährliche Steigerung des Einkommens, etc. Ausgehend von den gleichen Parametern werden in der folgenden Arbeit zwei Szenarien behandelt. Im ersten Szenario verwenden beide Haustypen zur Beheizung Gas, im zweiten Szenario wird Heizöl als Grundlage herangezogen. Für beide Szenarien müssen lediglich der Verbrauch, sowie der Preis des verwendeten Rohstoffes angepasst werden.

Aus beiden Investitionsalternativen resultieren zwei Nutzenfunktionen, die mittels Kapitalwertmethode abgezinst und einander gegenüber gestellt werden. Der Schnittpunkt beider Funktionen offenbart den Wert des Risikomaßes, den das Individuum besitzt, wenn es in ein Passivhaus investiert.

Der Grundgedanke hinter dieser Arbeit ist, dass ein Passivhaus höhere Anschaffungskosten hat als ein Standardhaus, jedoch sind die Kosten des Heizwärmebedarfs wesentlich geringer. Als Folge ist der resultierende Nutzen aus der Passivhausinvestition anfangs geringer als der Nutzen der Standardhausinvestition. Durch die geringeren Heizwärmekosten des Passivhauses ist die Steigung der Nutzenfunktion höher als die des Standardhauses. Diese Tatsache führt dazu, dass sich beide Kurven in einem späteren Zeitpunkt schneiden, da der Nutzen des Passivhauses größer wird.

Eine weitere wichtige Tatsache ist, dass ein risikoneutrales Individuum die Investition prinzipiell nicht tätigen wird, da der Kapitalwert der gesamten Energieersparnis des Passivhauses gegenüber dem Standardhaus geringer ist als die Differenz der Investitionskosten.

Abschließend zeigt die vorliegende Arbeit in Kapitel 5, wie sich das Risikomaß, unter Veränderung einzelner Parameter, verhält.

Appendix B: Abstract – English

The main goal of this paper is to find the level of risk aversion which is required for an individual to choose to invest into a passive house over a standard house under uncertainty of electricity prices over future periods. The investment will be made under the assumption that the individual who has the option to invest into a home can choose between a home with passive standard and a "regular" home (in accordance with the "Energieausweis für Gebäude", OIB Richtlinie 6) but must choose to invest and cannot postpone the investment.

The future electricity price will be forecasted in a Monte Carlo Simulation where the electricity price follows a Brownian motion with drift. Additionally, it will be assumed that the individual's utility function which is required to find the level of risk aversion follows the theory of constant relative risk aversion where the downside of risks is weighted more than the upside of risks.

The scenario will also consist of a specific set of parameters (such as the drift rate of the Brownian Motion, the volatility of energy prices, different levels of interest rates for borrowing, as well as saving money, income and yearly income increase, etc.) which shall correspond to real world values.

In order to find the value of risk aversion at which an individual will decide to invest in a passive house, the expected net present value of utility as a function of risk aversion for two different investments must be made: the first function which results from an investment in a standard home, and second the function which results from an investment in a passive house. The point where the two functions intersect (and the expected net present value of utility from the passive house investment becomes larger than that of the standard home investment) will show the corresponding degree of risk aversion should an individual choose to invest into a passive house.

Furthermore it will be shown how the degree of relative risk aversion will change in correspondence to the changes made to certain parameters in the model.

Appendix C: Curriculum Vitae

Alexander Penzias

Mobile: +43 664 914 2974
E-mail: alexander.penzias@hotmail.de
Date of Birth: 12th of February, 1986
Citizenship: Austria
Marital Status: Single
Address: Stoesslgasse 2/8, 1130 Vienna

Professional experience:

Ortner Consulting July 2011–August 2011, **Abu Dhabi, UAE**
Junior Consultant January 2011-April 2011, **Abu Dhabi, UAE**
July 2010-October 2010, **Qatar/UAE**

- Completed a financial plan and a feasibility study for a German Company with 10,000 employees which led to a €2m investment
- Assistance in a project from a Portuguese refractory company
- Presentations created: research on waste management for EU-GCC environmental seminar in Muscat, water scarcity and water efficiency in Qatar, energy efficiency in Qatar
- Wrote Business plan for an education project in the UAE
- Publications: A Guide to Sustainable Concrete Production, From Cement and Aggregate Substitutes to Sustainable Production Methods, Qatar
- Market Entry Study for the Austrian Government, UAE

Erste Sparinvest **Vienna, Austria**
Internship September 2009

- Creation of a risk appetite index (analysis of the correlation between the excess return rate and the volatility of the US stock market) which was used as foundation for a trading system
- Econometric data analysis (Phillips curve and Okun's Law)
- Analysis of the correlation between real interest rate and real growth rate in selected emerging market countries

OMV Middle East **Abu Dhabi, UAE**
Internship July 2008

- Analysis of company hierarchies in the oil sector
- Creation of an evacuation and contingency plan for OMV offices in the vicinity of the UAE

Tradehub Middle East **Abu Dhabi, UAE**
Internship July 2007

- Assistant recruitment officer

PRO + CO Consulting **Vienna, Austria**
Internship July 2006

- Administrative office work

Austrian Armed Forces **Vienna, Austria**
Military Service January 2005–September 2005

Education:

2005-2012	University of Vienna, Faculty of Economics, International Business Administration ▪ Specialization in Controlling and Energy & Environmental Management ▪ Wrote Master's Thesis on "Risk aversion, energy price uncertainty and passive house investment" ▪ Creation of a mathematical model
2002-2004	High School until graduation with IB in Vienna at Bundesgymnasium Fichtnergasse, 1130 Vienna
1996-2002	German International School (Deutsche Schule Tokyo & Yokohama) in Tokyo/Japan until GCSE
1992-1996	Elementary schooling in Karachi/Pakistan and Vienna/Austria

Qualifications:

Computer literacy:	Windows, OSX, MS Office, SAP (basic knowledge)
Languages:	German and English bilingual French written and spoken Basic Japanese
Recreational activities:	Team captain of the school basketball team of the German International School, Jogging, Biking, Tennis, Skiing, Books about astrophysics and economy, Aquaristic
Extracurricular activities:	participation at the IBC Europe challenge