

Henrik Jaldell\*

# Cost-benefit analyses of sprinklers in nursing homes for elderly

**Abstract:** The risk of dying in fires in nursing homes is six times the risk of dying in fires at home in Sweden. One way to reduce this risk is to install fire sprinklers. This study measures the benefits using value of full lives, life years and quality adjusted life years (QALYs) for deaths and injuries. The results show that sprinklers are cost-effective in newly built nursing homes no matter what value of life is used. However, if sprinklers are installed in already existing buildings, they are cost-effective only if the value of a statistical life is used.

**Keywords:** elderly; fire safety; QALY; value of life.

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\*Corresponding author: Henrik Jaldell, Karlstad University – Economics, Universitetsgatan 1 Karlstad 651 88, Sweden, e-mail: henrik.jaldell@kau.se

## 1 Introduction

The risk of dying in fires in nursing homes is six times the risk of dying in fires at home in Sweden. The risk of being injured in nursing homes is even higher. The reason is of course that fire alarms do not help if people have difficulty moving around, have dementia or do not understand a fire is occurring. The residents will take longer to detect the fire, have slower reaction time, have longer movement time, have problems exiting the building, e.g. through windows or stairs, cannot themselves help in suppressing the fire, and cannot expect to get help from their fellow residents (e.g., FEMA, 1999). In 2.5–3 min the condition may be critical, and in this short period the fire and rescue service will not have arrived in normal cases, and nor will the nursing home personnel have time to get everybody out (Mostue and Stensaas, 2002).

Ways of reducing the risk are installation of smoke alarms with both sound and flashing signs, using exit drills, training of personnel and to install fire sprinklers. In the USA the risk of fatality is lower in nursing homes than in ordinary homes, and in nursing homes sprinklers have been shown to decrease the risk of fatality from 10.8 to 1.9 per 1000 fires (HHS, 2008). In Sweden only 10% of the nursing homes have sprinklers installed compared to about 75% in the USA. However, from an economic perspective such investments should occur if benefits

exceed costs and should not be installed if their costs exceed benefits. The benefits clearly depend on the value society places on elderly people living in nursing homes. One interesting, and hard to answer, question then is what explicit value should be set on this group. Should society value the elderly individual in the same way as an average individual, or should we use quality adjusted life years be used, which drastically discounts the value of this specific group with low health and few years to live?

The purpose of this study is to find out whether it is economically efficient to install sprinklers in elderly homes, both newly built and existing, in Sweden. The benefits of installing sprinklers are that more lives will be saved, fewer people will be injured and less property will be damaged. Since these benefits are measured in different physical values, these savings will be converted into monetary values to make it possible to compare the benefits with the monetary value of installation costs. The methodology used is thus an economic cost-benefit analysis. Another question that will be answered is how sensitive the results are to what value society set on the elderly people in nursing homes.

In economic cost-benefit analyses it is customary to treat lives in “full units,” that is “a life is a life” irrespective of age, income or other socio-economic factors. The standard approach is to use the value of a statistical life, VSL. In most evaluations this is not a problem. For example, in traffic safety projects there is normally no reason not to value saved lives on the basis of an average individual in society. However, when it comes to nursing homes the target group is really a special group. They are elderly and in poor health, both of which lead to the fact that they will live a very short time. The literature tends to deal with this in two ways: Reduce the VSL-figure according to an age effect (OECD, 2011), or use the value of statistical life years, VS LY, instead of VSL. Using VS LY in cost-benefit analysis has been proposed by some (Sunstein, 2004), but still cannot be considered a common recommendation for use in cost-benefit analyses (Viscusi, 2009).

Nursing homes in Sweden can be run by municipalities or private firms, and in both cases the money comes from the taxpayers via the city council. Should the managers of the nursing homes improve fire safety instead of improving the quality of health care? When it comes to evaluations of health care using health economic measures, the standard procedure is to use the change in quality adjusted life years (QALYs) as a measure of utility change. In this study the monetary value of benefits will therefore be measured using VSL, VS LY and QALYs for deaths and injuries. How these three measures affect the benefit side and the conclusions will thus be compared.

This study makes three main contributions. First, not many cost-benefit analyses of fire safety, especially sprinklers, have been done on nursing homes. Second, not many cost-benefit analyses compare the three methods of valuing

saved lives, VSL-VSLY-QALY, and how this affects the results. Third, to be able to set the quality of life weight for the QALYs, a thorough discussion of the problems of finding such a value for the elderly in nursing homes and burn patients is conducted.

Considering the cost side, modern sprinkler equipment has become much cheaper than older equipment, since a completely separate sprinkler water supply system has to be built into older sprinkler systems, but the existing water supply system can be used for modern sprinkler systems. With the modern system it is now possible to install sprinklers for a reasonable cost in already built elderly nursing homes.

The results show that benefits exceed costs for sprinklers in newly built nursing homes no matter what value of life is used. However, if sprinklers are installed in already existing buildings, net benefits are positive only if the value of a statistical life is used. For VSLYs the results show that costs are nearly equal to benefits, but for QALYs they are not. So the main conclusion of the paper is that the results depend on the value society puts on the lives lost of elderly.

Section 2 discusses the empirical findings on how to value the elderly in nursing homes when it comes to the physical and monetary values of VSL, VSLY and QALY. Section 3 provides evidence of fire sprinkler effectiveness. Section 4 presents the data, the calculations and the results. Section 5 contains various sensitivity analyses using Monte Carlo simulations, including varying the discount rate, the effectiveness rate and the cost figures. Section 6 concludes the paper with a discussion of the findings.

## 2 Valuing elderly people in nursing homes

Several studies show that people in general value age groups differently. Most studies find that children are valued higher and the elderly are valued lower than middle-aged people. Considering stated preference studies where the respondents have to prioritize between different age groups in different choice sets, Johannesson and Johansson (1997), in a study on health investments, found that the lives of 40 70 year olds were equivalent to that of one 30 year old. The corresponding figure was around 2.5 in a stated preference study by Johansson-Stenman and Martinsson (2008) on traffic safety projects. Carlsson, Daruvala and Jaldell (2010a), in a similar stated preference study on fire and traffic safety, reveal that 10 year old children are worth 3.3 times as much as 70 year olds, and that 40 year olds are worth 2.3 times as much as 70 year olds. All these three studies find that the relative value of a saved life decreases with age, but Cropper,

Aydede and Portney (1994) show that the utility attached to saving an anonymous life is a hump-shaped function of the age of the person saved. Saving the lives of eight, 11 and seven 60 year olds are considered equivalent to saving the life of a 20-year old, a 30-year old and a 40 year-old, respectively.

The literature on the relationship between age and value of a statistical life (VSL) is extensive, both in terms of theoretical models (e.g., Jones-Lee, 1989; Johansson, 2002) and empirical investigations (e.g., Krupnick, Alberini, Cropper and Simon, 2002; Alberini, Cropper, Krupnick and Simon, 2004; Aldy and Viscusi, 2007). Two recent surveys came to different conclusions about the value of the elderly compared to other adults depending on the method used. Krupnick's (2007) review of stated preference studies concludes that: "The fact that the studies that focus on this issue are split in their findings is further evidence that the senior discount effect, if it exists, is not robust" (p. 275). Aldy and Viscusi's (2007) review of revealed preference labor market studies concludes that: "The labor market VSL increases with age, peaks in mid-life, and subsequently declines" (p. 257). Pearce (2000, p. 23), surveying three UK and one Canadian stated preference studies, concludes that "– WTP falls with age, but only after age 70," which is highly relevant for this study. Leiter (2011) in a recent stated preference study of snow avalanche risks in Austria shows that VSL varies with age if the hazard rate is age specific, but not if it is not age specific. The age specific effect, which is lower for those aged 63+, and higher for those aged 18–24 and 55–62, comes from focusing on the individual skiers, while the age-independent effect comes from focusing on non-skiers.

However, these studies have not led to many policy implications, and the reason is probably that it is very hard for decision-makers to explicitly state that some people are worth less. For example, a negative public reaction was received when the US Environmental Protection Agency discounted the life of the elderly by 37%, and therefore later abandoned this discounting (OECD, 2011). However, no such reaction was provoked by the European Commission's (2001) recommendation of an age-adjustment factor of 0.7 for valuing elderly people in environmental cost-benefit analyses, or by the factor of 0.75 for the elderly in Canada (OECD, 2011).

As a first alternative caution will be exercised and a lower value for people in elderly homes will not be stated explicitly. But what monetary value should be chosen? The only official value in Sweden is the one used for the transportation sector where the risk value was 21 million SEK in 2006 (SIKA, 2009).<sup>1</sup> This value is close to the median value of 23 million calculated by Hultkrantz and Svensson

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<sup>1</sup> 21 million SEK was equal to 2.3 million USD and 2.0 million EUR both adjusted for PPP in 2006.

(2012) in a meta-analysis using nine recent selected Swedish studies with a total of 29 VSL estimates. The OECD (2011) lists different official values for some countries. The Swedish value is higher than the value used by the UK Department of Transport (£1 million) and the European Commission recommendation of €1–2 million, lower than the official values used by different US agencies ranging from US\$5–7.5 million and the values used in Canada of C\$6.5 million, but quite close to the value used in Australia of A\$3.5 million and to the value of US\$3.5 million for the EU-27 recommended by the OECD study in question.<sup>2</sup> The differences in values can hardly be explained by different income levels and different risk levels.<sup>3</sup>

There are also reasons to believe that VSL should vary depending on different objective risk levels for different contexts, but also subjective risk perceptions when it comes to feelings such as dread, fear, knowledge, familiarity, voluntariness and control. Should, then, the official Swedish VSL which is derived mainly from studies in road traffic environments, and not in fires, be used? Unfortunately, avoiding fire risk has not been studied much, and the few studies points in different directions. Savage (1993) discovered differences in the relative WTP for reducing risk in the hazard contexts domestic fires, stomach cancer and road and aviation accidents in a study where respondents were supposed to divide \$100 among the four risk contexts. He found that, due to a lower perception of dread and other unknown aspects, respondents had a statistically significantly lower WTP for fire safety projects than for highway safety projects.<sup>4</sup> In a stated preference study using repeated contingent valuation questions, Carlsson, Daruvala and Jaldell (2010b) found that the VSL for risk of fatalities in fires was only 2/3 of that for fatalities in road traffic. However Chilton et al. (2002) detected no major differences in risk valuation for risks of railways, domestic fires, fires in public places, and roads. Carlsson, Daruvala and Jaldell (2010a) found no difference

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2 Of course the different country values fluctuate with the exchange rates. The exchange rates for January 2012 are: 1 €=SEK 8.8=1.3 US\$=1.3 C\$=1.2 A\$.

3 The risk of a traffic accident for example is quite similar considering per capita and per vehicle-km for the UK and Sweden, but the average EU risk is higher, and Australia and Canada have similar risk levels and income levels, all according to IRTAD (2010). Another factor not taken into account here, and rarely in international comparisons, is that the VSLs normally are given in consumer prices (since revealed and stated preference studies consider consumers' willingness to pay), that is including taxes. The consumer tax levels are quite different between countries; Sweden has a normal value-added-tax of 25%, while some states in the USA have no sales tax at all.

4 Savage explains the perhaps intuitively surprising finding that a lower degree of knowledge of the risk leads to a lower WTP, by arguing that people may be more willing to spend money on things that they know will have an effect.

in risk priorities between fire and traffic risks in a choice experiment taking age effects and difference between saving lives and reducing injuries into account.

An alternative to using the value of a statistical life is to use the value of a statistical life year (VSLY). VSLYs may be estimated directly from revealed and stated preference studies, but this has not been done in many studies.<sup>5</sup> Instead, it is more reasonable, today, to calculate VSLYs from official VSLs, since there are many more VSL-studies and the official VSL-values therefore should be more reliable. The standard approach to calculating VSLY is to assume that the VSL is true for the average age of the fatalities, and then treat the VSL as a sum of the expected life years. Assuming a discount factor and taking the yearly fatality rate into account, the VSLY can be calculated as:

$$\text{VSLY} = \frac{r \cdot \text{VSL}}{[1 - (1+r)^{-L}]}$$

where  $r$  is equal to the discount rate and  $L$  is equal to life years saved (Aldy and Viscusi, 2007).<sup>6</sup> The implicit assumptions here are that the discount rate is constant for a full lifetime, and that it is reasonable to assign an equal value of VSLY for every year lost. The choice of the size of the discount rate is important. For example, using 2% instead of 4% for the Swedish VSL of 21 million, changes VSLY from SEK 1.1 to 0.8 million, or by more than 25%. However, economic theory suggests that the interest rate consists of two parts, where one part is due to the diminishing marginal rate of consumption over time and the other part is a pure time preference. Mason, Jones-Lee and Donaldson (1999) suggest that it is only the pure time preference rate that should be used in these calculations, since it can be assumed that the VSLY will increase by the marginal rate of consumption over time.<sup>7</sup> It should also perhaps be relevant to assume a decreasing interest rate over time instead of a constant interest rate, i.e., use hyperbolic discounting. However, the relevance of these proposals for people in nursing homes with few expected life years can be questioned, and therefore a constant

<sup>5</sup> One rare recent example is Desaigues et al. (2011) that estimated VSLY directly from WTP surveys on reducing air pollution in nine European countries. They conclude that a reasonable value for Western Europe is €40,000. (Using an interest rate of 4% and a life expectancy of 40 years, this corresponds to a VSL of about €1.1 million).

<sup>6</sup> Mason et al. (2009) argue that if a declining VSL over age is assumed such information should be incorporated in the calculations. However, this is not regarded here, firstly because the evidence on declining VSL is not clear, and secondly that Mason et al. find that taking this fact into account does not in a substantial way.

<sup>7</sup> In the UK it is assumed that the social discount rate is 3.5%, of which 1.5% is due to pure time preferences.

interest rate will be assumed here. Since it cannot be taken for granted that VSL is independent of age, VSLY could also be dependent of age. Hammit (2007, p. 238) concludes from Krupnick (2007) that “– suggests that VSLY increases with age.” and from Aldy and Viscusi (2007) that “– over the older ages during which VSL decreases, the rate of decrease in VSL appears to be somewhat more rapid than the rate at which life expectancy decreases, suggesting that VSLY decreases with age.” Hammit also notes that the revealed preference studies using labor market data do not include elderly retired people, and that the choice is arbitrary between VSL and VSLY. This is not true when it comes to the elderly living in nursing homes, since the life expectancy in elderly homes is very short, only about three years.

However, in health economics it is standard procedure to use quality adjusted life years, QALYs, as measures of benefits. That is, not only expected saved life years, LY, are considered, but also how the quality of life changes, QoL.<sup>8</sup> The average QoL in Sweden is somewhere around 0.8 (see references below), but considering elderly people living in nursing homes the QoL value research indicates that it should be lower, due to being older and having reduced physical and mental health. Using the EQ-5D, Burström, Johannesson and Diederichsen (2001a) estimated health-related QoLs for different diseases, age and socioeconomic groups in Sweden. For the age group 70–79 the index was found to be 0.79, and for the age group 80–88 it was 0.74. For all age groups the index for those classifying their health as “rather poor” was 0.46, and for those classifying it as “very poor” it was 0.17. Using their regression results (*ibid*, p. 631, table 7), the indices for the age group 70–79 with “poor health” and “very poor health” were calculated to be 0.46 and 0.23, respectively, while for the age group 80–88 the corresponding indices were 0.45 and 0.21. (The youngest age group 16–19 had the highest index with 0.91 and the group including the average age of a Swede had an index of 0.86. The index was lower for females than for men.) In another similar study by Burström, Johannesson and Diederichsen (2001b) the index for the age group 70–79 was 0.71 and for the age group 80–84 it was 0.61. For all ages the index for those reporting “rather poor” was 0.33 and for those reporting “very poor” 0.20. Using their regression results (*ibid*, p. 65, table 7) the indices for the age group 70–79 with “poor health” and “very poor health” were 0.32 and 0.20, respectively, while for the age group 80–88 the corresponding indices were 0.27 and 0.14. In a Finnish study on the quality of life for elderly critically ill patients, Kaarlola, Tallgren and Pettilä (2006) found that the Quality of life-index decreased from 0.68 for 65–69

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<sup>8</sup> The scale goes from 0 (=dead) to 1 (=full health). This scale is presented here even if some authors have used a scale from 0 to 100.



year olds down to 0.61 for 80–94 year olds. The index was about 0.15 points higher for the same age groups in the general population.<sup>9</sup> Sullivan, Karlsson and Taft (2002) used the SF-36 to find norms for physical and mental health quality indices for the Swedish population. For physical health the quality index could be standardized to 0.54 for people in the age group 75–79 and 0.48 for people 80 and over. The mental health quality indices were higher by 0.68–0.69. In a German study of quality of life in the older population, Hunger et al. (2011) found the mean EQ-5D index to be 0.76 with a mean age of about 74 years. The mean index was found to be decreasing (non-linearly) up to the age of 87 (about –0.14), and then somewhat increasing. Borglin, Jakobsson, Edberg and Rahm-Hallberg (2006), in two postal surveys of the quality of life among older people in Sweden, found a Quality of life-index of 0.75 in the first. In the second, the index for present life was 0.52–0.60 and for life span 0.86–0.89 (females–males), showing a decrease over time. The mean ages were 85 and 83, respectively. Another Swedish survey used a sample recruited from a politically affiliated organization for seniors (Retired People's Organisation, PRO), but found a fairly high current quality of life-index of 0.74 (Hagberg, Hagberg and Savemann, 2002). It can be compared to a life span quality of 0.75 and an outlook-of-life-index of 0.69. Unfortunately, none of these Swedish surveys made adjustments for where the older people lived. However, measuring health using a quality of life index may not be straightforward. Nord (1996) summarized health state scores for different QoL-index models. For people with severe problems the index value varied between 0.20 (EuroQol) and 0.77 (15 D). Nord's conclusion is that none of the models are appropriate and he adds that a rule-of-thumb-model (with values of 0.67–0.85) may also be used.

So what about people living in nursing homes? Using a postal survey, Hellström, Andersson and Hallberg (2004) found no difference in the quality of life-measure QoL (both mental and physical) when comparing older people in Sweden living at home and receiving help to those living in special accommodation. However, they found lower values for those needing help compared to those not needing help in the same age group. In another postal survey, Hellström, Andersson and Hallberg (2004) showed that the total score for quality of life, QoL, was about 15 % lower for older people needing help compared to those not needing help. Tseng and Wang (2001) found that the standardized score for quality of life among the elderly in nursing homes in Taiwan was 0.53.

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<sup>9</sup> Halvorsrud and Kalfoss (2007) reviewed measurements of quality of life in older adults. They listed different methods used and tried to set a quality mark on each study, but unfortunately they did not list and compare the absolute value of quality of life from each study. (Many studies do not list the absolute value, but they just compare correlations between different methods used.)



So is it fair to use lower QALYs for the elderly, due to shorter expected life and worse health? Nord, Pinto-Prades, Richardson, Menzel and Ubel (1999) list four arguments. The first is the fair innings argument, which says that all people should have a standard life time of about 70–75 years (not more). The second is a severity argument, which says that it would be better to increase people from low QALY indices to high. The third is the realization-of-potential argument, which says that you should not be punished for not being able to reach a high QALY. The fourth is an inequality aversion argument, which says that QALYs among people should be as equal as possible. Having lower priority preferences for the elderly may also be attributed to a productivity argument according to Tsuchiya (1999). When it comes to sprinklers in homes for the elderly, the severity argument and the realization-of-potential argument are valid. They have lower QoL-indexes on average, but they also have no possibility of attaining a high QoL-index. So it could therefore be argued that a larger weight should be given to people in elderly homes. The empirical evidence also points in this direction (Dolan, Shaw, Tsuchiya and Williams, 2005), but choosing specific weights is hard (Lancsar, Wildman, Donaldson, Ryan and Baker, 2011). One suggestion is to set the weight to 1 for all life saving programs, but whether this corresponds to people's preferences is a matter of discussion (Nord, Pinto-Prades, Richardson, Menzel and Ubel, 1999; cf. Johannesson, 2001). The fair innings argument instead works in the opposite direction for people living in elderly homes, since it is reasonable to assume that they have had their "fair" share of life already. As discussed below, some, but not all, empirical evidence also points in this direction. Ubel, Richardson and Pinto Prades (1999), however, argue that the public anyway have sympathy for the disabled because they have *not* had their fair quality of life. That death is the worst state, as shown by Ebrahim et al. (1991), is also questionable. They let people value different health statuses on a scale between 0 (best) and 12 (worst). For those older than 75, death was given a valuation of 9.0, which was the same valuation given to a health status described by "Confined to bed. Has slight pain which is relieved by aspirin." The health status described as "Unconscious, but not aware or in pain" got a valuation of 10.5. These health statuses are very likely not uncommon in elderly homes and can be interpreted as a QoL-index with negative numbers.

Having discussed the average weight for people living in nursing homes, the next question is how many QALYs will be lost if there is a fire and people get injured. Unfortunately, there have not been many studies of this, even if burn treatment can be very hard to undergo. McMillan (2002) uses burn treatment as an example of negative QoL-weights "The possibility of a negative quality of life is important in QALY theory. Some medical treatments (e.g., for severe burns) have recovery periods during which (arguably) the patient's quality of life is worse

than being dead. In such situations, the first QALYs produced may be negative.” (*ibid*, p. 19). Baker et al. (2008) compared two different ways of measuring quality of life: Quality of Life Questionnaire (QLQ) and SF-36, for young adults burned as children. The results showed that for SF-36 the value was the same as for non-burned, but for QLQ the results showed lower quality of life for burned than for non-burned. Bron and Hay (2001) analyzed whether artificial skin substitute (Transcyte) is more cost-effective than traditional human cadaver allograft (HCA), for patients with total body surface burns. The interesting result here is that, while still in hospital the quality of life is 0.65, but directly after hospital treatment it is 0.54. Sanchez and Bastida (2007) calculated QALYs for burn patients in Valencia, Spain. The QoL-index gain with treatment was 0.26 measured with visual analogue scale (VAS) and 0.36 with time trade-off (TTO). These measures can be seen as the minimum levels of a loss in the QoL-index when burned. The average QoL-index after treatment was 0.87, which means that a maximum level for getting burned could be a loss of around 0.3–0.5. Miller, Romano and Spicer (2000) calculated a QoL loss for children suffering from burns to be 0.11.

The empirical evidence above is not clear, not for elderly people in general, people living in nursing homes, or for burn treatments, so it is hard to choose specific QoL-weights. In this study the chosen QoL-weights are 0.6 for the mean value for the elderly in nursing homes. A severe injury is measured by a reduced QoL-weight by 0.5 for 2 months, and a slight injury by a reduced QoL-weight by 0.1 for 2 weeks. Since these reduction numbers can be discussed, sensitivity analyses of these weights have been performed using Monte Carlo simulations.

If a QALY number has been decided upon for the elderly in nursing homes, what monetary value should be attached to this figure? One way, as for life years, is a direct approach using stated preference willingness to pay questions to find monetary values of QALYs. So far there have not been many studies directly estimating a WTP for QALYs, especially not in Sweden. One recent study incorporating many European countries including Sweden, is the EuroVaQ-project (Donaldson et al., 2010). They estimated the WTP for a QALY both indirectly by first stating standard game and time-trade questions and then letting respondents value the answers in monetary units and directly answer different WTP questions for different QALY-changes and risk levels. Unfortunately, the project did not sum up the estimations to one specific monetary number for Europe or for the countries involved. The (trimmed) mean results for Sweden from the indirect method vary between US\$19,000 and 63,000, and from the direct methods between US\$4000 and 58,000. The variation in the results seems to reflect the non-linear preference scale for QoL-changes, which is reflected in the discussion on QoL above. There seem to be non-linearities when it comes to both the

absolute and the relative QoL-changes. The WTP for a 0.1 QoL-change is not the same when the change goes from 0.4 to 0.5 compared to 0.7 to 0.8, and the WTP for a 0.2 change is not twice as high as a 0.1 change. Similar difficulties of finding a monetary value for QALYs using stated preference techniques is the conclusion by Pinto-Prades, Loomes and Brey (2009) when trying to estimate a WTP for QALY in Spain.<sup>10</sup>

Another way is to use the value of a VSL and recalculate this into QALYs in the same way as VSLYs are calculated but also taking into consideration that the average QALY is lower than 1 VSLY. Donaldson et al. (2010) used this method to calculate the value of one discounted QALY to SEK 1.02 million, which is considerable higher than both the direct study results above and higher than the (unofficial) Swedish threshold of SEK 500,000 (NBHW, 2010). This is the method that will be used in this study.

### 3 Evidence of sprinkler efficiency

Hall (2010) recently analyzed American fire department statistics from 2003 to 2007 to study the size of the impact of sprinklers and other automatic fire control equipment. He found a very large effect on the number of fatalities. For example, restaurants and bars decreased the number of deaths down to 0, i.e., by 100%, hospitals by 72%, homes by 80%, warehouses and offices by 75% and industrial buildings by 25%. The effect of saved property is also very large when buildings with functioning sprinklers were compared to buildings without sprinklers (or without a functioning sprinkler). For example, sprinklers reduced lost property value by 63% for school and healthcare buildings, by 68% for residential buildings and by 22% for industrial buildings. The problem with this study is that it does not hold other factors affecting the saved value constant, such as response time and strength and size of the fire service and the fire and other fire protective equipment.

Similar effects to those found by Hall were obtained earlier from US data. Butry (2009) used in his cost-benefit analysis of American sprinklers, effect relationships, derived from data for 2002 to 2005, to show a 100% decrease of fatalities in homes with sprinklers, 57% fewer people with injuries and 32% less property damage. However, smoke detectors were not controlled for. Thomas (2002) also discovered similar positive results in an analysis of US fire

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**10** A theoretical analysis of the problem (impossibility?) of finding a societal WTP for a QALY is discussed by Dolan and Edlin (2002).

data from 1983 and about 10 years onwards. Similar positive results in terms of sprinklers were obtained by Melinek (1993) in a study of British fires that concluded that if all houses used sprinklers, fatalities would be reduced by half. Mostue and Stensaas (2002) in a Norwegian experiment concludes that with sprinklers at least 50% fewer people will die from fires in nursing homes. Nystedt (2003) shows that residential sprinklers reduce the risk of death by 53% in Sweden. A study by Duncan, Wade and Saunders (2000) from New Zealand takes into account whether the building has smoke detectors or not. The results show that sprinklers only in buildings could reduce fatalities by 80%, and in combination with smoke detectors by 84% (only smoke detectors reduce the number of fatalities by 53%). A Canadian study by Richardson (2007) shows that the number of deaths from fires in care homes for the elderly is 65% lower with sprinklers installed compared to care homes without sprinklers. Property damages are 40% lower, but personal injuries are larger in care homes with sprinklers installed. Despite the positive effect of the sprinklers, it is not certain that it is economically efficient to install sprinklers in buildings because the cost is too high. Butry (2009) found that installing private homes with sprinklers was economically efficient, whereas a previous study by Harmathy (1988) did not find it profitable. A Swedish cost-benefit study by Juås (1994) used American and Canadian results for the early 80s showing a 44% reduction in deaths and 65% reduction in property damage when sprinkler were used. The costs of sprinkler installation in newly built residential houses (both detached and apartments) were generally too large compared to benefits. For hospitals and nursing homes the costs were roughly equal to benefits. Mostue and Stensaas (2002) estimate that the ratio between benefits and costs is between 1 and 4.5 for nursing homes in Norway. All of these studies used the average value of statistical life for valuing saved lives. Williams, Fraser-Mitchell, Campbell and Harrison (2004) found that benefit-cost ratios in the UK for detached houses and apartments were below one, but sprinklers were economically efficient for nursing homes for the elderly (2.0), children (4.5) and people with reduced mobility (1.1). Gros, Spackman and Carter (2010) performed a cost-benefit analysis of sprinklers in a specially planned construction area in the UK. They showed that sprinklers in different homes were not economically efficient with benefit-cost ratios from 0.4 to 0.8. The closest to economic efficiency were sprinklers in so-called “social housing.” The Center for Medicare and Medicaid Services at the US Department of Health and Human Services in their final rule on requiring all long term facilities to be equipped with sprinkler systems by August 13, 2013, calculated the benefit-cost ratio to 1.2 assuming 82% reduction in fatalities with sprinklers and using a 3% discount rate (HHS, 2008).

## 4 Data, assumptions, calculations and results

All analyses in this section are based on an assumption of a typical elderly home building of 2000 m<sup>2</sup> with 40 apartments of 50 m<sup>2</sup> each. This assumption may seem limiting when it comes to general conclusions, and a sensitivity analysis is therefore performed in Section 5 to compare the results here with a smaller and a larger building.

### 4.1 Costs

A reasonable technical life of a sprinkler is 25 years according to fire experts. The following costs apply in newly constructed elderly homes per apartment, according to the Swedish sprinkler promotion society of residential sprinklers:<sup>11</sup>

Installation costs	8000 SEK
Delivery inspection	100 SEK
Maintenance cost	100 SEK
Service agreements (per year)	80 SEK

The present value of these costs is 10,053 SEK, and the annuity of cost (including value-added tax of 25%) is 804 SEK calculated using a discount rate of 4%. The costs are assumed to be 37.5% higher for installing residential sprinklers in existing buildings (called renovation here), which means 11,000 SEK for installation costs and an annuity of 1004 SEK.

The costs should be seen as approximations and best guesses of the mean values. In an actual bidding process for a real installation of sprinklers, the firms' bids will of course differ and the suggested figures above, even if they are accurate estimates, will not be true in all places all over Sweden. To take this into account, sensitivity analyses, using Monte Carlo simulations where the costs fluctuate, will be performed in Section 5.

### 4.2 Benefits – “full” life

In order to compare costs, which of course are expressed in monetary units, benefits are also calculated in monetary terms. The benefits consist of the effect on risk

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<sup>11</sup> All monetary figures are in 2010 prices. In October 2012 1 US\$=6.70 SEK.

times the monetary value. The effect is calculated in terms of risk reduction in the form of fewer fatalities, fewer serious injuries, fewer minor injuries, and less property damage.

Section 3 describes different studies that show divergent results on the efficiency of sprinklers. For simplicity, we have chosen to use the same effect figures of 70% for both personal and property damage. A sensitivity analysis of this assumption is performed in Section 5.

To calculate the property damage, no new investigation has been made. Instead, the value of 648 SEK per apartment from Juås (1994) is used, and add an additional 6% to take indirect costs of insurance administration and reimbursement apartments into account. The average value of the property damage is therefore 960 SEK per apartment in 2010 prices.

The calculation of the marginal effect of reduced injury has been done by first calculating the risk of harm that would have existed if no one had had sprinklers. This risk is then reduced by the effect of sprinklers and multiplied by the respective monetary value of injury.

The Swedish Civil Contingencies Agency's fire death statistics (2000–2008) have been used and the source for severe and light injuries is the same agency's response data from fire and rescue services for the years 1999–2008. The mean number for these years has been used. The fire death statistics show that the number of fatalities is approximately 2.7 times higher than the fatalities reported in the response statistics. This means that some data are missing and therefore the same correction has also been made for severe and slight injuries.

In 2010, 95,600 people lived in so called "special housing" for the elderly (National Board of Health and Welfare 2010a). In this study it is assumed that only one patient lives in each apartment. The death and injury risk in special housing for the elderly is much higher than for residents in ordinary Swedish homes. The risk of death in elderly homes is six times greater and the risk of other injuries is ten times greater. When the marginal effect of sprinklers is calculated, the fact that about 10% of the elderly homes already have sprinklers installed (without this protection there would have been even more deaths and injuries today). The corrected figures in Table 1 takes this aspect<sup>12</sup> into account, including the likelihood that there are probably missing values for severe and slight injuries in the data set.

Monetary values used in the study are the official Swedish values from the transport sector. The reasons for using these are that they are most reliable, since most valuation studies for deaths and injuries have been done within the transport sector when it comes to revealed preference studies, and the transport sector

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<sup>12</sup>  $x*(1-effect)*(share\ of\ buildings\ with\ sprinklers)+x*(share\ of\ buildings\ with\ sprinklers)=y\ x*(1-0.7)*0.1+x*(1-0.1)=4.9\ x=5.3.$

**Table 1** Risk of personal injury and property damage.

	Number per year (actual)	Number per year (corrected)	Risk per person Elderly homes (corrected)	Risk per person All other homes (corrected)
Deaths	4.9	5.3	0.0000512	0.00000849
Severe injuries	4.1	12.0	0.0001167	0.00001062
Slight injuries	29.8	87.2	0.0008486	0.00007924
Property value per apartment	960 SEK	960 SEK		

**Table 2** Effect with full life calculations using sprinklers.

	Risk reduction effect (70% effect)	Risk reduction effect per apartment (70% effect)	Marginal effect in monetary values
Deaths	-3.7	-0.0000551	924 SEK
Severe injuries	-8.4	-0.0000878	416 SEK
Slight injuries	-61.1	-0.0006387	159 SEK
Property value per apartment	-672 SEK		672 SEK
<i>Total</i>			2171 SEK

is used as the scenario when it comes to stated preference studies. The monetary risk values used are 23.8 million SEK for deaths, 4.4 million SEK for severe injuries and 0.2 million SEK for slight injuries as used by the transport sector in Sweden (SIKA, 2009).<sup>13</sup>

Savings on hospital and medical costs, ambulance care, fire service, etc. must also be added. Using a Swedish cost-of-illness study of the costs of fires (MSB, 2008), these costs have been calculated for the age group in question in this study. For deaths 125,000 SEK have been added, for severe injuries 310,000 SEK, and for slight injuries 36,000 SEK.

Using the above information and assuming a 70% risk reduction effect the benefits summarize to 2171 SEK (see Table 2), which is larger than the costs. That there are positive net benefits for sprinklers in nursing homes.

### 4.3 Benefits – life years and QALYs

If QALYs are to be used as a measure of reducing injuries, the total effect of sprinklers would be reduced due to three aspects. First, the life expectancy of an

<sup>13</sup> Values from 2006 (SIKA 2009) have been adjusted for inflation to 2010.



average death in traffic is 37 years. The average age of the elderly is much higher and thus their life expectancy is much shorter. Based on the average age and life expectancy in Sweden, the average for that age group is 6.9 years. Second, life expectancy in elderly homes is even shorter. Using the data from the National Board of Health and Welfare (NBHW, 2001), in which data are available for different age groups and types, the average life expectancy has been calculated to be 3.2 years. Third, using QALYs does not only take life expectancy into account, but also quality of life. The weight of quality of life is equal to one for a perfectly healthy human. That the residents of elderly homes do not have a quality of life weight equal to one is self-evident, but it is hard to find empirical evidence for what number to use. The main problem is that the surveys used are not well-formulated for elderly people. Here, the weight 0.6 is adopted for the quality of life in elderly homes and use the information from the studies surveyed in Section 2.

The effect of sprinklers measured as life years and QALYs can be divided into an effect on fatality, an effect on serious injuries and an effect on slightly injured. The effect on fatality is obtained by multiplying the present value of 3.2 years loss of life by the effect of sprinklers on deaths. The effect on severely damaged is calculated by multiplying 2/12 with the effect of sprinklers on the severely injured, and the effect on slightly injured is calculated by multiplying 2/52 with the effect of sprinklers on minor injuries.

Table 3 contains the calculations of monetary values for life years and QALYs. Using life years gives, as expected, a higher monetary value of the effect of sprinklers than using QALYs. One problem with the monetary values of life years is that the values for other injuries, except deaths, become relatively high, since people in elderly homes are only expected to live for another 3.2 years. This will have the effect that deaths and slight injuries have about the same value, which does not seem plausible. Therefore a corrected value is also calculated where the monetary

**Table 3** Effect on life years and QALYs with sprinklers.

	Monetary values “life” years per apartment	Monetary values using corrected “life” years per apartment	QALY per apartment	Monetary values with QALYs per apartment
Deaths	142 SEK	142 SEK	0.0000683	106 SEK
Severe injuries	416 SEK	63 SEK	0.0000073	11 SEK
Slight injuries	159 SEK	24 SEK	0.0000025	4 SEK
Total injuries	717 SEK	229 SEK	0.000078	121 SEK
Hospital costs etc.	(incl. above)	(incl. above)		55 SEK
Property value per apartment	672 SEK	672 SEK		672 SEK
<i>Sum</i>	<i>1389 SEK</i>	<i>903 SEK</i>		<i>849 SEK</i>

values for severe and slight injuries have been reduced by the same percent as for deaths. This is probably too much, but the value can then be seen as a minimum value for life year calculation. However, this corrected value is still higher than the total monetary value using QALYs. One additional setback is that the property values share of the total value increases from 32% to between 50% and 79%. Using QALYs as a measure of welfare therefore indicates that personal values are worth much less than material values.

The benefit-cost differences and ratios for the eight cases are shown in Table 4. Sprinkler installations in newly built homes for the elderly seem to be net beneficial for society regardless of the quantitative measure used. However, when it comes to installing sprinklers in existing elderly homes, this is only true when using “full” life values or uncorrected expected life years.

## 5 Sensitivity and robustness analyses

The values calculated in Table 4 have been checked by using several sensitivity and robustness analyses. First, the results have been checked for a change in the interest rate from 4% to 3%. Second, the results have been checked for the lowest effect values for sprinklers that can be used and still obtain positive net benefits. Third, Monte Carlo simulations have been run for the cost figures assuming different costs with triangle and uniform distributions, as well as for the effect of sprinklers assuming different effects and therefore leading to different benefit values. Fourth, a Monte Carlo simulation has been run for the weights of quality of life assumptions in the QALY calculations. Fifth, to only rely on results from a typical

**Table 4** Benefit-costs relations.

	Monetary values “full life” per apartment	Monetary values “life” years per apartment	Monetary values using corrected “life” years per apartment	Monetary values with QALYs per apartment
Benefits	2171 SEK	1389 SEK	903 SEK	849 SEK
Costs new	804 SEK	804 SEK	804 SEK	804 SEK
B-C difference	1367 SEK	585 SEK	99 SEK	44 SEK
<i>B-C ratio</i>	2.70	1.73	1.12	1.06
Benefits	2171 SEK	1389 SEK	903 SEK	849 SEK
Costs renovation	1044 SEK	1044 SEK	1044 SEK	1044 SEK
B-C difference	1127 SEK	345 SEK	-141 SEK	-196 SEK
<i>B-C ratio</i>	2.08	1.33	0.86	0.81

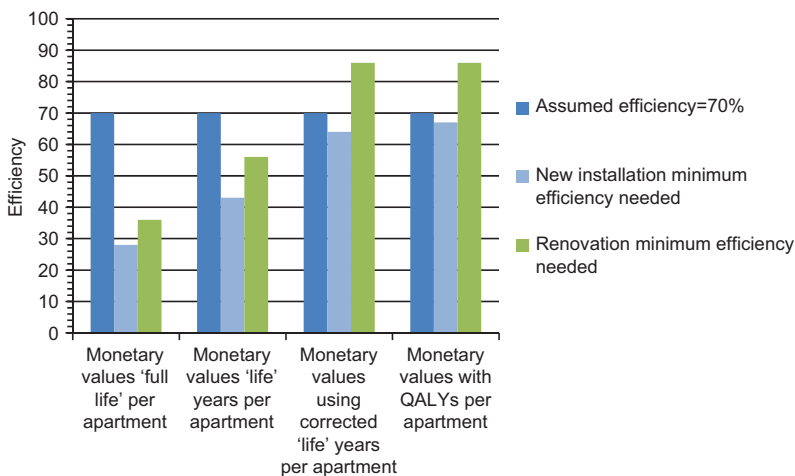
size of an elderly home may seem limited. Therefore two additional assumptions about the size of the elderly home have been considered; one smaller and one larger. Finally, on the 17 November 2011 only reduced ignition propensity (RIP) cigarettes were allowed in Sweden (and in the EU). An analysis of what effect this may have on the benefit-cost ratio has also been performed.

## 5.1 Changing the interest rate

Using a lower interest rate (3% instead of 4%) leads to lower annuity costs. The lower interest rate also decreases the benefit values using life years and QALYs (but not full lives). However the two effects are not enough to make the below one B-C ratios turn to over one. The lowest B-C ratios are now 0.92 and 0.88.

## 5.2 Changing costs and effects

Figure 1 shows the efficiency percentages needed to still have positive net benefits. Using “full life” values, the benefit-cost ratio will still be above 1 even down to sprinkler efficiency of 28% and 36% for new and renovation installations, respectively, which means that the results are robust when it comes to the efficiency assumption. Using QALYs the results are not robust; for new installations almost 70% efficiency is needed, while for renovations 86% efficiency is needed.



**Figure 1** Efficiency of sprinklers needed to still have positive net benefits.

That all sprinkler installations would cost the same irrespective of the firm doing the work, where in Sweden the installation takes place, the local competition among the firms and the design of the building is not realistic. To take this fact into account, Monte Carlo simulations (10,000 repetitions) have been done where the costs vary in certain intervals, assuming a uniform distribution.<sup>14</sup>

It is also reasonable not to consider the benefit side as fixed, but as consisting of random variables. Therefore Monte Carlo simulations ( $n=10,000$ ) have been also performed using different assumptions about the benefit side variables. Looking at data for personal injuries for the years 2000–2008, the yearly injuries vary quite a lot for all three categories, and it is not unreasonable to see them as uniformly distributed. For the injury variables a uniform distribution has been chosen with the range between upper and lower values being the same. The number of dead, for example, varies between 1 and 10 yearly in 2000–2008. For property loss there are no data making it possible to estimate a distribution. Instead a triangular distribution is assumed where the value varies  $\pm 25\%$ . The effect from sprinklers is also assumed to vary according to a triangular distribution  $\pm 10\%$ -units, and the current sprinkler frequency is varied according to a triangular distribution of  $\pm 5\%$ -units.<sup>15</sup>

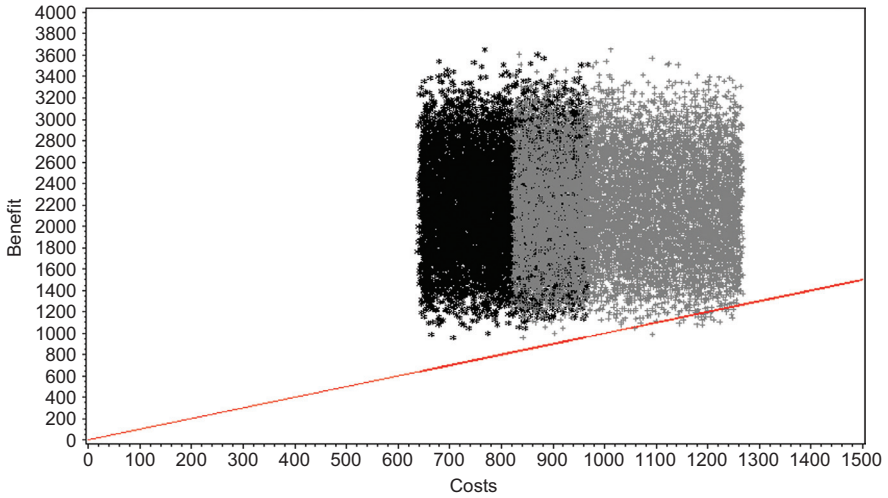
The results from the Monte Carlo simulations are shown in Figures 2–5. It can be seen that the benefits using “full lives” monetary and benefit values are in almost all cases above costs no matter if new installation, renovation, triangular or uniform distribution are assumed. For “life years” the benefits are greater than the costs in almost all cases of new installations and in about 85–90% of renovations. For “corrected life years” and “QALYs” the distribution for new installation about three fourths and two thirds, respectively, are above the benefit-cost ratio equal to one line. Using costs for renovation installations, only 15% and 10%, respectively, of the results have a benefit-cost ratio above 1.

### 5.3 Changing the size of the building

Costs have also been calculated for one smaller and one larger elderly home. The smaller home has 13 patients in an area of 520 m<sup>2</sup> and the larger home has 100 patients in an area of 4000 m<sup>2</sup>. Since there are fixed costs per home the annuity cost increases to 892 SEK for the smaller home and decreases to 604 SEK for the

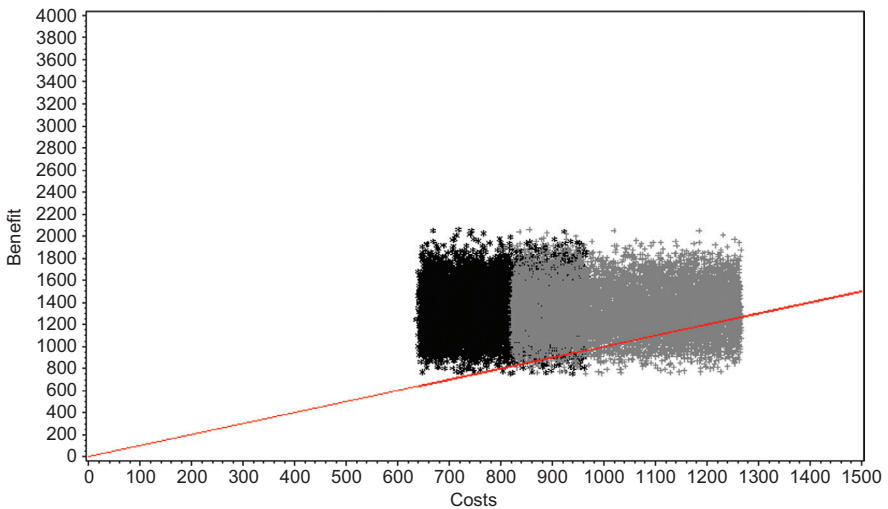
<sup>14</sup> A triangular distribution has also been tested. The variation is smaller using a triangular distribution, but the Figures 3–6 look very similar.

<sup>15</sup> It seems reasonable to vary expected life year in elderly homes and the different QALY-weights in a Monte Carlo simulation. This was also tested, but the results were very similar to those in Table 12 and are therefore not discussed in the paper.

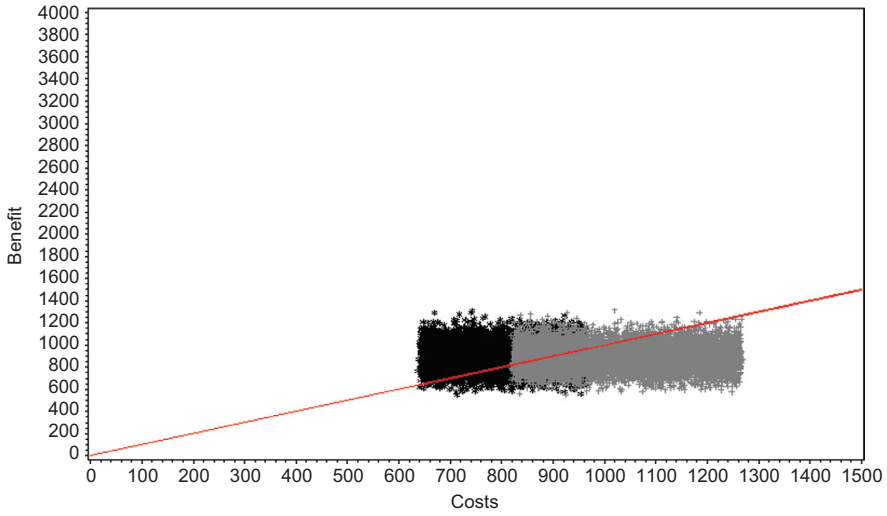


**Figure 2** Benefit-costs comparisons with Monte Carlo simulations ( $n=10,000$ ) for benefits="Full life" and costs (black=new, gray=renovation). The red line is where the benefit-cost ratio is 1.

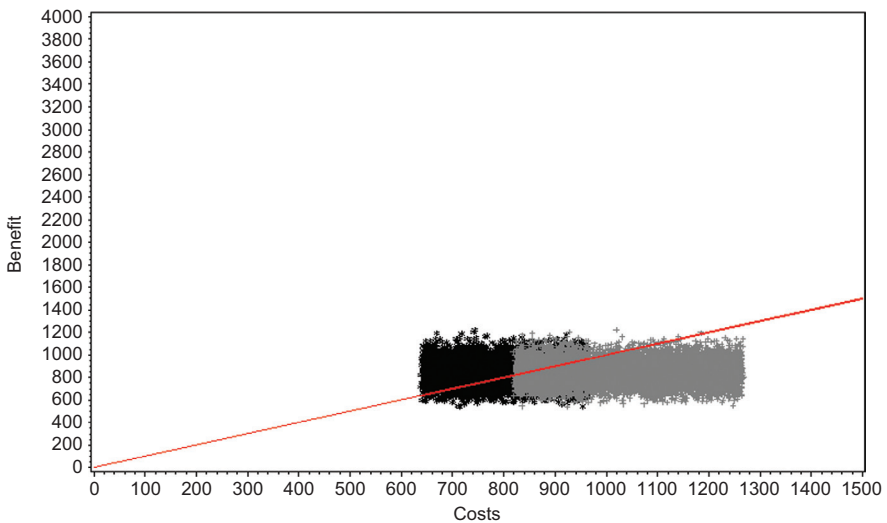
larger home. The results indicate that for "larger" homes the B-C ratio is above 1 no matter which benefit measure is used, i.e., sprinkler installations in larger homes are net beneficial for society. For "smaller" homes, however, the benefit-cost ratios are only above 1 for benefits measured using "full life" and "life years."



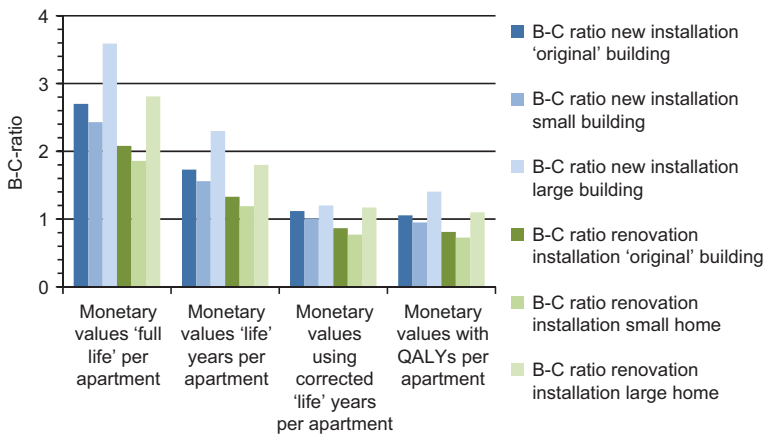
**Figure 3** Benefit-costs comparisons with Monte Carlo simulations ( $n=10,000$ ) for benefits="Life years" and costs (black=new, gray=renovation). The red line is where the benefit-cost ratio is 1.



**Figure 4** Benefit-costs comparisons with Monte Carlo simulations (n=10,000) for benefits=“corrected Life years” and costs (black=new, gray=renovation). The red line is where the benefit-cost ratio is 1.



**Figure 5** Benefit-costs comparisons with Monte Carlo simulations (n=10,000) for benefits=“QALY” and costs (black=new, gray=renovation). The red line is where the benefit-cost ratio is 1.



**Figure 6** B-C ratios for different sizes of homes for elderly.

## 5.4 Assuming less risky cigarettes

The last robustness test considered is the introduction of reduced ignition propensity (RIP) cigarettes. This is the only cigarette type allowed to be sold in the European Union after 17 November 2011. Of course there will be “old” cigarettes still in circulation, private imports of other cigarettes will still exist and it is also possible that there will be some illegal import of other cigarettes which will be sold in the EU including Sweden. However, for people living in nursing homes, it is reasonable to assume that they will not engage in private import and that they will almost only buy legally sold cigarettes. Given this assumption, how much will the injuries and damages from fires decrease with the new legislation? Here, 40% is used. The figure comes from Finland where the RIP cigarettes were introduced in April 2010 and the number of fires are said to have been reduced by over 40% (European Commission, 2011). From Table 2 the risk of injury and damage in elderly homes is known. Looking at the fire statistics most fire deaths are due to smoking, but smoking is not the main cause of the other fire related personal injuries.

Assuming a 40% reduction of smoking-related injuries and damages due to RIP cigarettes the total marginal effect is 24% lower, which affect all comparisons of benefits to costs. The results indicate that sprinklers are still net beneficial valuing benefits with “full life,” and valuing benefits with “life years” when building new elderly homes. But for the rest of the cases sprinklers are not socially profitable.



## 6 Conclusion

If sprinklers were to be installed in all nursing homes this would save three to four lives annually, and reduce the number of severe injuries with seven to eight annually with expenditures of totally round 1000 million SEK summed over 25 years. One conclusion that can be drawn is that there are many uncertainties about variables and parameters used in the cost-benefit analysis. There are uncertainties about how to convert a monetary value of statistical lives to a monetary value of statistical years and, even more difficult, to a monetary value of QALYs. There are uncertainties in finding quality of life weights to be used for the QALY. Not much research has been done on finding a value for elderly people, and especially for elderly people in nursing homes. Even if the standard methods (e.g., time-trade-off and standard gamble) used today to find quality weights seem to result in different weights depending on the method used, the problem of finding appropriate ways to value the lives of elderly people in nursing homes is greater. There are also uncertainties about changes in QALYs from fires, when it comes to directly lost QALYs and won QALYs from burn treatment. More research in this area seems appropriate. However, the sensitivity analyses using Monte Carlo simulations in this study show that perhaps the chosen QALYs does not affect the outcome of the cost-benefit analysis too much.

The main conclusion of this study is that the result of the cost-benefit analysis of sprinkler installations in nursing homes for elderly depends on what value you put on the elderly. Treating them as having the same value as an average person makes the benefits being greater than the costs, considering sprinkler installation in existing buildings. However, when using remaining life years, VSLYs, avoiding fire deaths brings the benefits closer to the costs. If quality adjusted life years, QALYs, are used instead, as is standard in health economics, the benefits are lower than the costs. When performing a study like this, one would ideally want to have the “correct” ethical value for the elderly in nursing homes. One would also like to know how people’s preferences about using VSLs, VSLYs, and QALYs vary. More research on these topics is wished for.

In other words, it is the value society put on the elderly that decides the outcome of this cost-benefit analysis and therefore affects the decision on whether to install sprinklers or not. This conclusion seems to be robust when it comes to variations in the installation cost levels and efficiency levels for sprinklers in reducing fires.

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