How to correctly assess mortality benefits in public environmental policies

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Abstract

This paper concerns the difficulty of taking long term effects on health into account in an economic valuation. A methodology is developed and enables the time lapse between implementation of an abatement policy and achievement of all of the expected mortality-related health benefits to be estimated. The main findings are that long-term health benefits calculated by standard methods and widely applied to adverse environmental effects should be corrected downwards when incorporated in an economic analysis. The magnitude of correction depends on the discount rate, on technical choices dealing with epidemiology and on the method chosen to assess mortality benefits.

Keywords: cost-benefit analysis, discounting, life expectancy, long-term mortality.

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1 Introduction

Improvements in data collection, the accumulation of epidemiological studies and an increased concern for public health have resulted in better knowledge of long-term human health outcomes resulting from past exposure to adverse environmental factors. Studies of effects on health of alcohol or food consumption, smoking, environmental and occupational exposure to adverse substances have generally shown that long-term effects on health (i.e. chronic health outcomes resulting from long-term exposure) are much more severe than short-term ones (i.e. acute health outcomes immediately following exposure). They account for almost all the health benefits of giving up smoking and more than 70% of the health benefits of air pollution abatement (Ostro and Chestnut, 1998; Holland and King, 1999; Sommer *et al.,* 1999). The assessment of future health benefits should therefore incorporate long-term effects on health as a prerequisite for evaluating the desirability of a public environmental policy.

Long-term effects are characterized by what we call here "the time lapse factor": the substantial time that elapses between the implementation of a health / environmental policy and the achievement of full health benefits. Failure to adequately take into account the time lapse factor may lead to incorrect assessment of future benefits. Ignoring the specific nature of long-term effects is equivalent to considering that all the benefits will accrue immediately after implementation of a policy, and, as a result, overestimating them. Since chronic effects result from cumulative exposure, the health expenditures observed over a given year do not depend solely on exposure to adverse substances in that year alone. This clearly implies that a decrease or an abatement in exposure will not fully and immediately reduce the associated health expenditures, but rather that there will be a lapse of time before this is achieved. This has major consequences for economic valuation and therefore for public decision-making, particularly when discount rates are high, and could be an important issue in certain environmental policies.

Several studies have recently assessed long-term effects on health of air pollution by multiplying the number of attributable cases by the appropriate monetary values (Ostro and Chestnut, 1998; Holland and King, 1999; Sommer *et al.*, 1999).[1] Most studies do not mention that the results represent benefits that can be obtained in the long run. Problems arise when the long-term nature of the underlying health outcomes is neglected and the overestimated benefits are compared with the correctly estimated costs of a policy, thereby biasing the analysis. The degree of overestimation of these benefits is of particular interest.

This paper proposes a methodology that takes into account the time lapse associated with long-term effects on mortality by calculating the number of deaths avoided. We depart from Leksell and Rabl (2001) who propose a method based on years of life saved, and assess a number of deaths avoided during the implementation of a health policy in a dynamic perspective. We perform a sensitivity analysis with respect to various parameters, especially the magnitude of the time lapse and the value of the discount rate – both of which are subject to severe uncertainty.

The paper proceeds as follows. Section 2 shows how the reduction in exposure to adverse environmental factor affects mortality. Section 3 presents a general framework for health benefits assessment when there are long-term effects. Section 4 gives the conclusions.

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[1] The European Union followed this route exclusively until 1995, in particular within the ExternE framework. Since 1997, approaches using deaths avoided and years of life saved have been employed simultaneously.

2 How reduction in exposure to an adverse environmental factor affects mortality

Consider a decision-maker who wants to implement an abatement policy that would generate short-term and long-term health benefits by improving the health of the population. In order to estimate the health benefits arising from the policy, one first has to estimate the health outcomes by combining epidemiological data, initial exposure level and exposure reduction. In this section, we show how to carry out this evaluation and introduce the problem of effects on mortality.

2.1 The concepts of relative risk and death rates

The concept of Relative Risk (RR) is crucial in epidemiology, and is the starting point of the analysis. It can be defined as the risk, for a population exposed to a specific factor, of being affected by an event (R^E), divided by the same risk for a population not exposed to this factor (R^{NE}). This concept applies for both short term effects on health (within hours or days after exposure) and long-term effects on health (over years or even a lifetime). It should be noted that the population is heterogeneous, hence the RR may vary within the population. We consider here that an average RR can be defined for a given health indicator depending on the current average level of exposure. $RR^E \equiv \frac{R^E}{R^{NE}}$ denotes this relative risk for a level of exposure E.

As the level of exposure changes, the RR varies according to two key variables: the length of the latency period between past (long-term) exposure and its future health consequences, and the way the human body heals itself after a period of lower exposure. Thus, we can assume that the RR of a health indicator follows a declining pattern:

$$RR_t = g(E, \Delta_E, t) \tag{1}$$

where

- RR_t denotes the relative risk t years after reduction,
- E is the initial level of exposure,
- Δ_E stands for the fractional exposure reduction ($\Delta_E \in [0,1]$),
- g is a functional form, with $\partial g/\partial t < 0$, $\partial g/\partial E > 0$ and $\partial g/\partial \Delta_E < 0$.

It should be noted that at the date of reduction $t = 0$, $RR_0 \equiv RR^E$ and that RR_t approaches $RR^{(1-\Delta_E)E} \equiv \frac{R^{(1-\Delta_E)E}}{R^{NE}}$ as $t \to \infty$.

This paper deals with mortality only. Hence, reduction in exposure to an environmental factor affects mortality rates by modifying the relative risk of death. Let $D_0(x)$ be the mortality rate observed at age x before the reduction, broken down into one part affected by the reduction and another part independent of the reduction:

$$D_0(x) = D_0^R(x) + D_0^I(x) \tag{2}$$

where

- $D_0^R(x)$ is the death rate at age x for causes directly linked to the factor in question,
- $D_0^I(x)$ is the death rate at age x for unrelated causes.

To make this distinction clearer, it should be remembered that accidental deaths, for instance, are not affected by a reduction in air pollution exposure, nor are deaths due to environmentally induced cancers affected by safety improvements in road infrastructures.[2]

The directly linked death rate t years after implementation of the policy varies according to RR_t:

$$D_t^R(x) = \frac{RR_t}{RR_0} D_0^R(x) \tag{3}$$

It will vary from $D_0^R(x)$ when t=0 to $\frac{RR^{(1-\Delta_E)E}}{RR_0} D_0^R(x)$ when $t \rightarrow \infty$.

By definition, deaths due to unrelated causes are considered not to be affected by the environmental factor: $D_t^I(x) \equiv D_0^I(x)$, for all t. Hence, the total death rate at age x and t years after the reduction is:

$$D_t(x) = D_0^I(x) + D_t^R(x) \tag{4}$$

To characterize accurately the way RR_t varies, i.e. the shape of function g, would require extensive information and a lengthy observation period. We present a simple general approach before considering possible extensions.

2.2 Instantaneous and complete removal of risk

Lightwood and Glantz (1997) estimate a mortality risk function based on the meta analysis of 7 studies of giving up smoking, an impact with instantaneous and complete risk removal. Eq. (5) is derived from their risk function, and presents a general equation for an impact with these characteristics:

$$RR_t = RR^{NE} + (RR^E - RR^{NE}) \times \exp(-\frac{t}{\tau}) \tag{5}$$

where

- t is the time since the activity was stopped,

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[2] This is not absolutely true, since the medical resources freed by a decrease in one health problem might at least theoretically be used to treat another.

- RR^{NE} denotes the relative risk of an impact-related illness for those not exposed to the impact (by definition $RR^{NE} \equiv 1$),
- $RR^{E} \equiv RR_0$ denotes the relative risk of an impact-related illness before the impact ceases ($t = 0$),
- τ is the time constant of the exponential function, assumed to be illness-dependent.

The estimates of τ differ in the literature depending on the illness considered. Lightwood and Glantz (1997) obtain 1.4 for stroke and 1.6 for acute myocardial infarction, Leksell (1998) cites between 4.3 and 6.5 for lung cancer, and Doll *et al.* (1994) between 10 and 15 for total excess risk. The negative exponential function in Eq. (5) is also found to fit adequately decay phenomena in other disciplines (physics, biology...), and is hereunder considered as benchmark.

Figure 1 indicates how the relative risk RR_t decreases with time according to Eq. (5), starting from RR^E down to the RR of non-exposed subjects ($RR = 1$). The results depend strongly on the value of τ, since it takes 7 years to reach $RR = 1$ when $\tau = 1$, but up to 45 years when $\tau = 10$.

[Figure 1 about here].

Although adverse health effects related to tobacco smoke are only long-term effects, adverse health effects are in general a mix of short-term and long-term effects. Short-term effects will disappear as soon as the exposure to the risk factor ceases while long-term effects will evolve gradually. Therefore, let us split $RR^E - RR^{NE}$ into two parts, with ${}^{ST}R^E$ denoting the short-term effects (i.e. less than one year) share and ${}^{LT}R^E$ the long-term effects (i.e. more than one year) share. Eq. (5) becomes:

$$RR_t = RR^{NE} + {}^{ST}R^E \mathrm{Max}(1 - t, 0) + {}^{LT}R^E \times \exp(-\frac{t}{\tau}) \qquad (6)$$

2.3 Extension to a non-instantaneous and incomplete removal of risk

For many risk factors, abatement policy constraints or technical constraints preclude instantaneous and complete exposure reduction. Examples of such policies are the introduction of filters that reduce industrial and car emissions, thorough vaccination campaigns, alcohol or tobacco prevention policies, regulations concerning exposure to toxic substances... Thus, we consider a gradual policy of duration p, i.e. that takes p years to achieve a fractional percentage reduction $\Delta_E \in [0, 1]$. Below, we consider the simplest case of a linearly decreasing reduction: each year, an additional reduction of Δ_E/p occurs. We consequently have to generalize Eq. (6) in two ways.

First, if we consider an incomplete reduction $\Delta_E < 1$, the relative risk will approach $RR^{(1-\Delta_E)E}$ in the long run following the negative exponential path:

$$RR_t = RR^{(1-\Delta_E)E} +^{ST} R^{(1-\Delta_E)E}\mathrm{Max}(1-t, 0) +^{LT} R^{(1-\Delta_E)E} \times \exp(-\frac{t}{\tau}) \quad (7)$$

Second, removal of the exposure is no longer considered instantaneous. It is supposed that a reduction of Δ_E will be achieved over p years following a linearly decreasing path (Δ_E/p every year $t \leq p$). The impact on the RR will be proportional to the decline during the p first years, and will fully apply after p years:

when $t = 0$, $RR_0 = RR^{(1-\Delta_E)E} +^{ST} R^{(1-\Delta_E)E} +^{LT} R^{(1-\Delta_E)E}$,
when $t = 1$, $RR_1 = RR^{(1-\Delta_E)E} + \left(\frac{p-1}{p}\right)^{ST} R^{(1-\Delta_E)E} + \frac{^{LT}R^{(1-\Delta_E)E}}{p}\left[(p-1) + \exp(-1/\tau)\right]$,
$\vdots$
when $t \leq p$, $RR_t = RR^{(1-\Delta_E)E} + \left(\frac{p-t}{p}\right)^{ST} R^{(1-\Delta_E)E} + \frac{^{LT}R^{(1-\Delta_E)E}}{p}\left[(p-t) + \sum_{h=1}^{t} \exp(-h/\tau)\right]$,
when $t \geq p$, $RR_t = RR^{(1-\Delta_E)E} + \frac{^{LT}R^{(1-\Delta_E)E}}{p} \sum_{h=t-p+1}^{t} \exp(-h/\tau)$.

where h measures time elapsed since/before the full implementation of the policy.

The general formulation becomes:

$$RR_t = RR^{(1-\Delta_E)E} + {}^{ST}R^{(1-\Delta_E)E}\mathrm{Max}(\frac{p-t}{p},0) + \frac{{}^{LT}R^{(1-\Delta_E)E}}{p}\sum_{h=t-p+1}^{t}\exp(-\mathrm{Max}(h,0)/\tau) \quad (8)$$

Figure 2 represents this effect for $\tau = 5$, ${}^{ST}R^E$ standing for 25% of total excess risk, and different values for p. For instance, the excess relative risk is divided by two after 2 years for $p = 1$, whereas it takes 13 years to obtain the same reduction if $p = 20$.

[Figure 2 about here].

This affects the rates of incidence of the relevant health indicators and therefore the number of years necessary to reap full health benefits from a reduction policy. We need to transform changes in death rates into deaths avoided, and then into a monetary value. This is done in the next section, which presents a framework specific to the problem at hand.

3 Inclusion of long-term effects within an economic assessment

In order to assess whether it is economically efficient to implement a given public environmental policy, its benefits must be compared to its costs. A cost-benefit analysis generally compares the future discounted costs and the benefits of a policy (see Gramlich, 1990; or Layard and Glaster, 1994 for a general overview). Although reduction in the level of exposure generates health improvements both in terms of mortality and morbidity, in this paper we are only interested in the challenge of properly assessing the benefits with respect to mortality.

3.1 Measuring decrease in mortality

Since our aim is to take into account the “time lapse factor”, a dynamic setting must be considered. Indeed, counting the number of deaths avoided makes sense for a given year, but since deaths avoided that year are in fact premature deaths avoided, they will inevitably occur in the future when the dynamic setting is accounted for. To assess the benefits in terms of mortality in a dynamic setting is more complicated than in the usual static framework. We propose an approach that solves this problem.[3]

3.1.1 Defining the problem

Deaths attributable to an adverse effect on health are generally assessed by considering the difference between the number of deaths observed in a population exposed to a given level of adverse environmental factor and the number of deaths that would occur in a non-exposed population. A monetary value for a death avoided is then used to compute the benefits corresponding to the mortality reduction, and the future discounted sum of these benefits can be used for a cost-benefit analysis. Holland and King (1998, 1999) and Olsthoorn *et al.* (1999) for the European Union, Ostro and Chestnut (1998) for the United States and Gynther and Otterström (1998) for Finland proceed in this way. This is incorrect when long-term effects are involved, since time lapses are ignored. Indeed, the decrease in RR^E will not immediately follow risk removal, but will occur progressively (see the general formulation of RR_t in Eq. (8)).

However, the problem of the time lapse factor cannot be solved easily just by extending calculations of the difference in number of deaths in a dynamic setting.

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[3] An approach based on the number of years of life saved is somewhet easier to implement. Indeed, every year, the total number of years lived by the population can be computed, in addition to the total discounted number of years of life saved by a given policy.

Indeed, consider a hypothetical cohort - initially in a steady state according to initial death rates observed in current mortality tables - which evolves according to the relative risk in Eq. (8). The annual number of deaths will first decrease as a consequence of the reduction of RR_t. Since these avoided deaths are simply postponed for the future, the cohort will reach a new steady state in the long run, where the annual number of deaths is the same as initially. Figure 3 shows how the number of deaths avoided evolves, for both instantaneous and complete risk removal and for immediate decrease in RR (this case is referred to as $\tau = 0$ in the sequel) in a cohort. When $\tau = 5$, it takes 7 years to reach the maximum number of deaths avoided whereas when $\tau = 0$, the maximum is reached in the first year and is twice as large. In both cases, the number of deaths avoided slowly decreases towards 0, which is reached about 60 years after the beginning of the policy.

[Figure 3 about here].

The number of deaths avoided the first year in the case $\tau = 0$ (see Figure 3) is the measure actually used in the literature, but it ignores time lapses. The benefits of a permanent policy are then (wrongly) computed by considering the flow of deaths avoided on this basis. The question of how to correctly count the number of deaths avoided in a dynamic setting and how to incorporate the time lapse factor clearly deserves attention.

3.1.2 Correctly counting the number of deaths avoided

When counting the number of deaths avoided, the variation process of the cohort is as follows.

- The cohort is initially in steady state. The number of persons of age x alive at date 0, $N_0(x)$, is computed from the product of all the survival rates before age x: $N_0(x) = \Pi_{y=0}^{y=x-1}(1 - D_0\,(y))N$.

- The number of persons of age x alive at date t is computed from the number of people of age $x-1$ alive at date $t-1$, which is affected by the survival rate of people of age $x-1$ at date $t-1$: $\forall x \geq 1$, $\forall t \geq 1$, $N_t(x) = (1 - D_t(x-1))N_{t-1}(x-1)$, with $D_t(.)$ as in Eq. (4).

- The number of deaths avoided at age x in year t is: $N_t(x)\left[D_0(x) - D_t(x)\right]$.

The number of deaths avoided (NDA) in year t is $\sum\limits_{x=0}^{\infty} N_t(x)\left[D_0(x) - D_t(x)\right]$, and increases until the cohort reaches another steady state corresponding to $RR_t = RR^{(1-\Delta_E)E}$. The number of deaths avoided can be expressed as:

$$NDA(E, \tau, \Delta_E, p, t) \tag{9}$$

For a given level of exposure E, the number of deaths avoided depends on the interaction of three parameters: the level of reduction (Δ_E), the length of time until the policy is fully implemented (p) and the parameter of the risk function (τ).

3.2 Sensitivity of the number of deaths avoided to the parameters

Let us first consider the influence of τ and p on the number of deaths avoided. Figure 4 represents the time necessary to obtain the full effects for $\tau = 5$ and different values of p (the time lapse also depends on RR^E, but so slightly that it does not show up in the Figure). French mortality data[4] were used to characterize the initial steady state.

[Figure 4 about here]

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[4] Data observed in OECD countries are very similar and allow generalization of the following results to developed countries.

If the reduction is complete and instantaneous ($p = 1$), we observe that it takes one year ($\tau = 1$) to seven years ($\tau = 10$) to obtain 50% of the maximum effect. If $p = 20$ years, the number of years is respectively 11 and 18. Thus it appears that when $\tau = 10$ instead of $\tau = 1$, it takes 7 more years to reach half the long-term benefits, and 30 more years to reach 99% of the long-term benefits. When the term of the policy is $p = 20$ (years) instead of $p = 1$, it takes about 11 more years to reach fifty percent of the long-term benefits.

Thus, economic consequences will be substantial, especially when discount rates are high, since the computations must then take into account time lapses of up to 30 years before including the entire benefits. Ignoring these delays leads to overestimating the total discounted number of deaths avoided.

3.3 The impact of the time lapse factor

Let us consider how time lapses may affect the total discounted number of deaths avoided, and the consequences of ignoring them. Let us assume for simplicity that $p = 1$.

The total discounted number of deaths avoided is:

$$TNDA(\delta,\ E, \tau, \Delta_E) = \left[\sum_{t=0}^{\infty} \frac{1}{(1+\delta)^t} NDA(E, \tau, \Delta_E, t)\right] \tag{10}$$

where δ denotes the annual discount rate. Discounting reflects the interaction of temporal preference relative to deaths avoided at different dates and the opportunity cost of economic resources devoted to the public health policy. The market interest rate is generally considered as a valid approximation and δ is the subject of a sensitivity analysis hereunder.

When the time lapse is ignored (i.e., $\tau = 0$), the total discounted number of deaths avoided is noted $TNDA(\delta,\ E, 0, \Delta_E)$. Clearly, $TNDA(\delta,\ E, 0, \Delta_E)$ exceeds

$TNDA(\delta,\, E, \tau, \Delta_E)$ for $\tau > 0$. The importance of the time lapse factor can be obtained by considering the ratio $R = \frac{TNDA(\delta, E, \tau, \Delta_E)}{TNDA(\delta, E, 0, \Delta_E)}$.

Formally, R depends on four parameters: E, Δ_E, τ, δ and simulations have been made taking different values for these parameters. Since no specific risk factor has yet been selected, we can consider that the policy-maker aims to reduce the relative risk from RR^E to $RR = 1$. We have considered a large range of values for the parameters:

- RR^E covers the range from 1 to 1.5 with a step size of 0.05,
- τ varies between 1 and 10,
- δ varies from 0.01 to 0.08 with a step size of 0.01.

R is plotted in Figure 5 for different values of δ and τ. The sensitivity to RR^E was found to be small, so results for different values of RR^E are not shown. As in Figure 2, ${}^{ST}R^E$ stands for 25% of total excess risk.

[Figure 5 about here].

R is found to lie between 0.62 and 0.98, with a value around 0.84 when $\tau = 5$ and $\delta = 0.04$. τ and δ have the strongest impact on the ratio. The lower τ, the higher R, which could be explained by the fact that small values of τ imply a rapid decrease in RR following the implementation of the reduction policy. The impact of the discount rate on the ratio is also negative, i.e. the larger the discount rate, the smaller the ratio. The conclusion is that the time lapse factor potentially has a significant impact on the estimation of health benefits when not properly accounted for.

3.4 Economic valuation of health benefits

The multitude of empirical assessments of a value for a prevented fatality (VPF) conducted so far have provided a large range of values (with a few exceptions between 0.7 and 6.1 million EUR). Such a large range should not be surprising, since there are major differences in methodology, in the attributes of the risk in question (whether or not it is controllable, familiar, dreadful, uncertain, voluntary, catastrophic, unfair, immediate, see Slovic, 1987) as well as in potential victim characteristics.

The proposed methodology could be adapted to any VPF, especially age-dependent VPF. Indeed, if the VPF at age x is denoted by $VPF(x)$, the total discounted benefits $B(.)$ associated to the reduction policy will be:

$$B(\delta,\ E, \tau, \Delta_E) = \sum_{t=0}^{\infty} \frac{1}{(1+\delta)^t} \left(\sum_{x=0}^{\infty} N_t(x) \left[D_0\,(x) - D_t\,(x) \right] VPF(x) \right) \tag{11}$$

Once the relevant VPF is chosen, the proposed methodology allows for a correct assessment of the benefits of a given environmental policy, and its comparison to the corresponding costs.

4 Conclusion

More and more evaluations of effects on health lead to the conclusion that externalities are important, especially long-term ones which account for most of the overall effects. Thus, public decision-makers should incorporate them in cost-benefit analysis for any projects involving health impacts. The delay problem we explore is found to be crucial from a decision-making standpoint. The purpose of the paper is methodological: we show how this problem can be handled and provide a framework which enables us to estimate future benefit trends. To take into account the time lapse factor, we need to consider an approach in terms of deaths avoided within a dynamic perspective. For a cost-benefit analysis, benefits corresponding to long-term health effects should then be corrected by a factor that is highly sensitive to the value chosen for the discount rate. Otherwise, consequences on public health may be dramatic, since a policy may generate a social loss rather than an expected social benefit.

The methodology can apply to various economic issues with long-term time lapse effects, like air pollution, chemical or harmful radiation exposure. Although only benefits linked with mortality have been explored here, long-term morbidity should also be studied. Unfortunately, very few epidemiological data exist for these effects on health, and their evaluation remains a topic for future research. The influence of long-term morbidity on the correction factor may well be surprising, since it largely postpones health costs for the future, which may appear desirable due to discounting.

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Figure 1: Variation in the Relative Risks versus τ

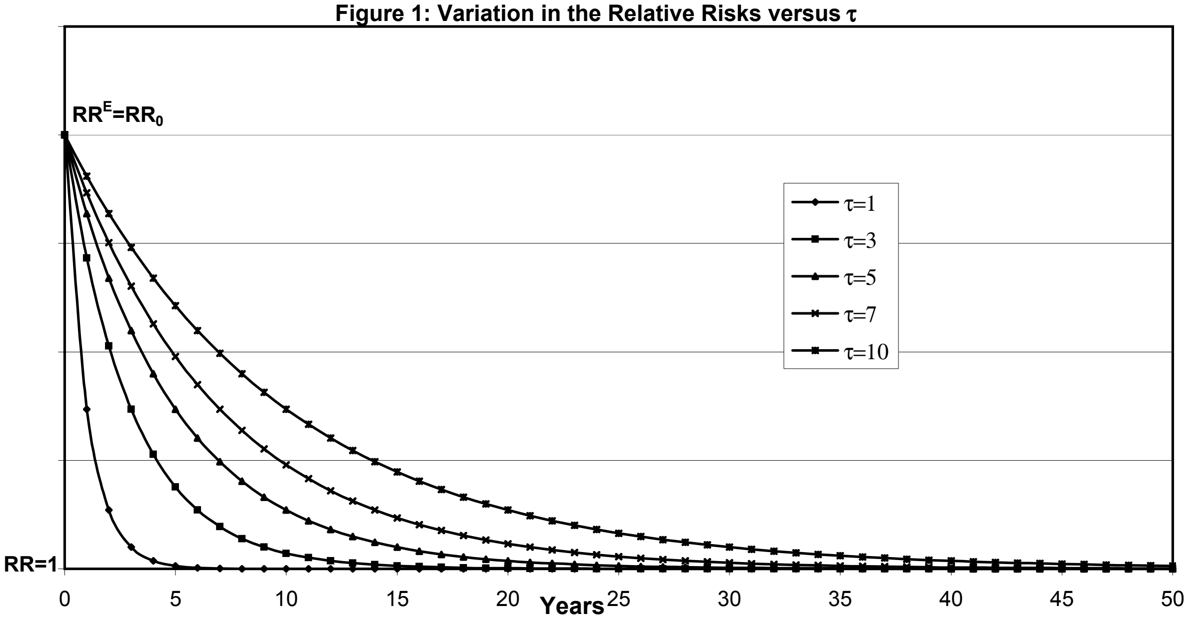

Figure 2: Variation of the Relative Risks for three values of p (τ=5)

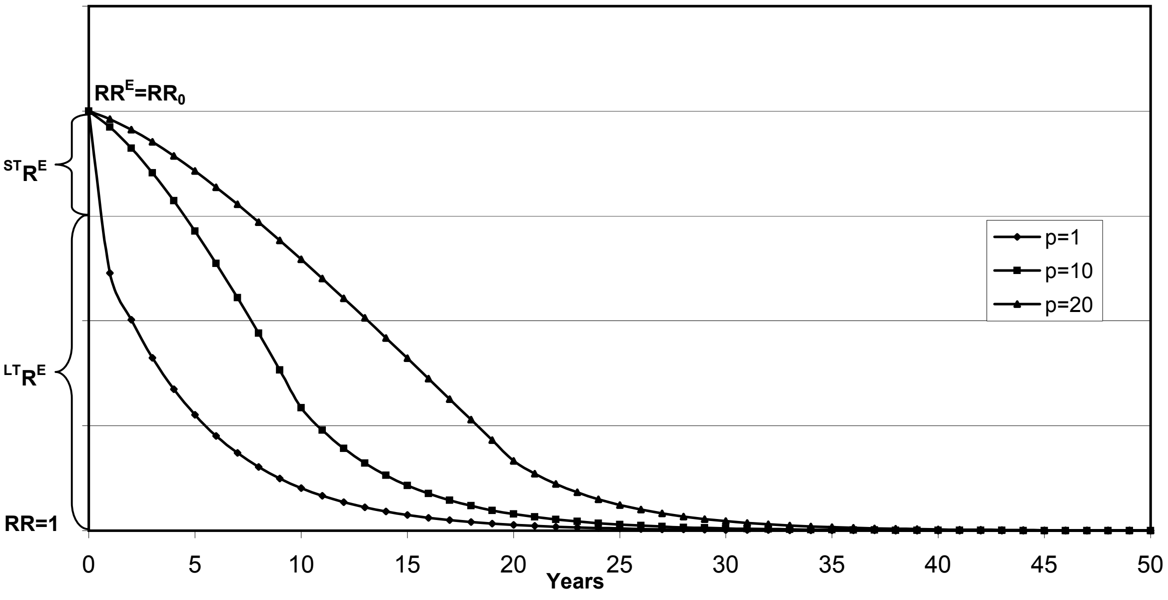

Figure 3: Variation in the annual number of deaths after complete and instantaneous risk removal

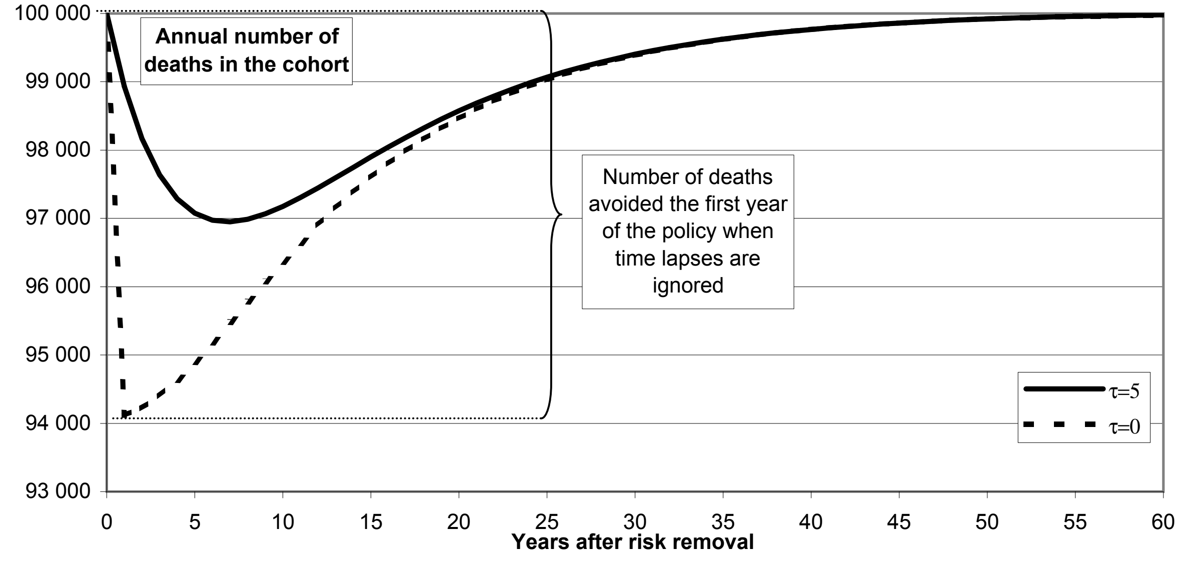

Figure 4: Time necessary to obtain the full number of deaths avoided (NDA) for different values of p (τ=5)

Figure 5: Influence of δ and τ on the ratio R