Bridging the micro-macro gap in population forecasting
Contract no. SP23-CT-2005-006637

Deliverable D13

Illustrative projections using MicMac: an example in the field of morbidity and mortality

Work Package 1/2
Multistate Methods and Microsimulation

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October 2009

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1 Introduction

Demographic projections are often confined to populations disaggregated by age and sex. The standard methodology among demographers is the cohort-component method. The basic approach is to distinguish the number of survivors of birth cohorts in a specific base year and to determine for each cohort and each projection year the number of persons by age and sex that (1) enters the population because of birth or immigration and (2) leaves the population because of death or emigration. Multistate models extend the cohort-component model that project a population by age and sex to a biographic projection model that projects the population by age, sex and other characteristics. In the multistate model, several states of existence are distinguished. As individuals move between the different states, the structure of the population changes over time. A sequence of state occupancies represents a lifepath or life trajectory of the population under study. In dynamic population projections, the distribution of the population among the different states is the outcome of transitions people make between these states. Each move from one state to another can be described by an event (for instance marriage, divorce or graduation). The rate of transition describes the propensity of the individuals under study to change their lifecourse. These rates determine the population dynamics. In demographic models transition rates always vary by age and sex, i.e. they are age-specific. As a result the multistate model gives at each age the distribution of cohort members among the different states distinguished. Formulated differently, it indicates how the characteristics of the cohort vary with age and time.

In demographic and biographic analysis, individuals and events are positioned in different time scales. Each time scale is related to a reference event and measures the time elapsed since the reference event in units of days, months or years. Age (individual time) and calendar time (historical time) are common time scales. If time is a continuous variable, the position of individuals and events is given in exact time. Exact time is also referred to as instantaneous time. If time is a discrete variable, the position is given in completed time units (e.g. years). The parameters of continuous-time transition models are instantaneous rates of transition or transition intensities.

The transitions that cohort members experience and the ages at which they experience the transitions determine how the distribution of members among different states changes as the cohort ages. The result is a cohort biography that gives for each age the distribution of cohort members among the functional states. The cohort biography is a collective biography, i.e. the combined biography of a group of individuals. This refers to population-based models of population dynamics. The same multistate model can be applied to a single individual to generate an individual biography. This biography gives for each age the probability that an individual cohort member occupies a certain state. This is an individual-based model.

The aim of MicMac is to bridge the gap between population-based models and individual-based models. The strategy adopted is to view population-level measures as expected values of individual-level measures. MicMac is a dynamic continuous-time multistate projection model that combines macro-level projections (the macrosimulation model Mac) and micro-level projections (the microsimulation model Mic). The link between Mac and Mic is formed by the transition rates by age, state of origin and state of destination. These transition rates often depend on risk factors. A risk factor is defined as a factor that is causally related to an outcome. Examples of risk factors are smoking behavior and Body Mass Index (BMI). The presence of a risk factor affects the probability of an event. Regression models such as survival models, duration models and event history models, link transition rates to risk factors. The outcomes of these models (i.e. differences in transition rates for different levels of the risk factors) are often expressed as relative risks.

As all dynamic demographic projection models, MicMac describes the development over time of a population of individuals broken down by certain demographic characteristics (e.g. age, sex, marital status, living arrangement, and the like). This multidimensional breakdown of the population defines a state space. The choice of the variables of the state space depends on the type of analyses for which MicMac will be used. As MicMac produces demographic projections, it is obvious that age and sex are included in the model as basic variables. Apart from purely demographic projections, MicMac is designed to be able to investigate the impact of lifestyle factors and other health determinants on the health status of different groups in the population. Therefore, depending on the application it also can take into account the variables disability status, marital status, living arrangement and number of children ever born, and the covariates (or risk factors) smoking, body mass index (BMI), educational status (as proxy for socio-economic status), and living arrangement. The categories of the variables form the states of the state space.

The empirical information on the variables included in the model may come from different data sources, such as registers, censuses or surveys. Using statistical techniques, data from different sources may be combined to calculate transition rates between the different states. For rather detailed state spaces, empirical information will not always be available for all variables and states. In that case exogenous information, such as expert opinions and results from literature reviews, can be added to the model.

To illustrate the possibilities and limitations of MicMac and to test the model in different national settings two case studies were carried out using data for the Netherlands and Italy. The first case study refers to analyses in the field of family and fertility, whilst the second case study includes analyses in the field of health.

The current document presents the second case study: using MicMac to compile scenarios of future trends in smoking, disability and mortality in Italy.

2 The research questions and state space

The general objective of the case study on scenarios of future trends in smoking, disability and mortality in Italy, is to illustrate the use of the micro-simulation model by its application to a real-world case. We study the effects of smoking cessation policies on mortality and disability in the Italian population. Point of departure is a two-sex model for the age range 0-100+, focusing on morbidity and mortality, disregarding fertility and migration. Although the simulation was compiled for the full age range from 0 to 100+, for the results we focus on the elderly.

2.1 Research questions

The main research question for this case study is the impact of smoking on disability and mortality. We chose this topic for three reasons: 1) it is generally acknowledged that smoking is important to population health, both as regards mortality as well as disability; 2) there is a large potential for health improvements through tobacco control policies and 3) population-wide effects of these policies are yet uncertain. How much will we gain, and when will we reach this? Tobacco control policies are universal in Europe, although their implementation varies a lot across countries. Table 1 shows the Tobacco Control Scale (TCS) for 18 European countries.

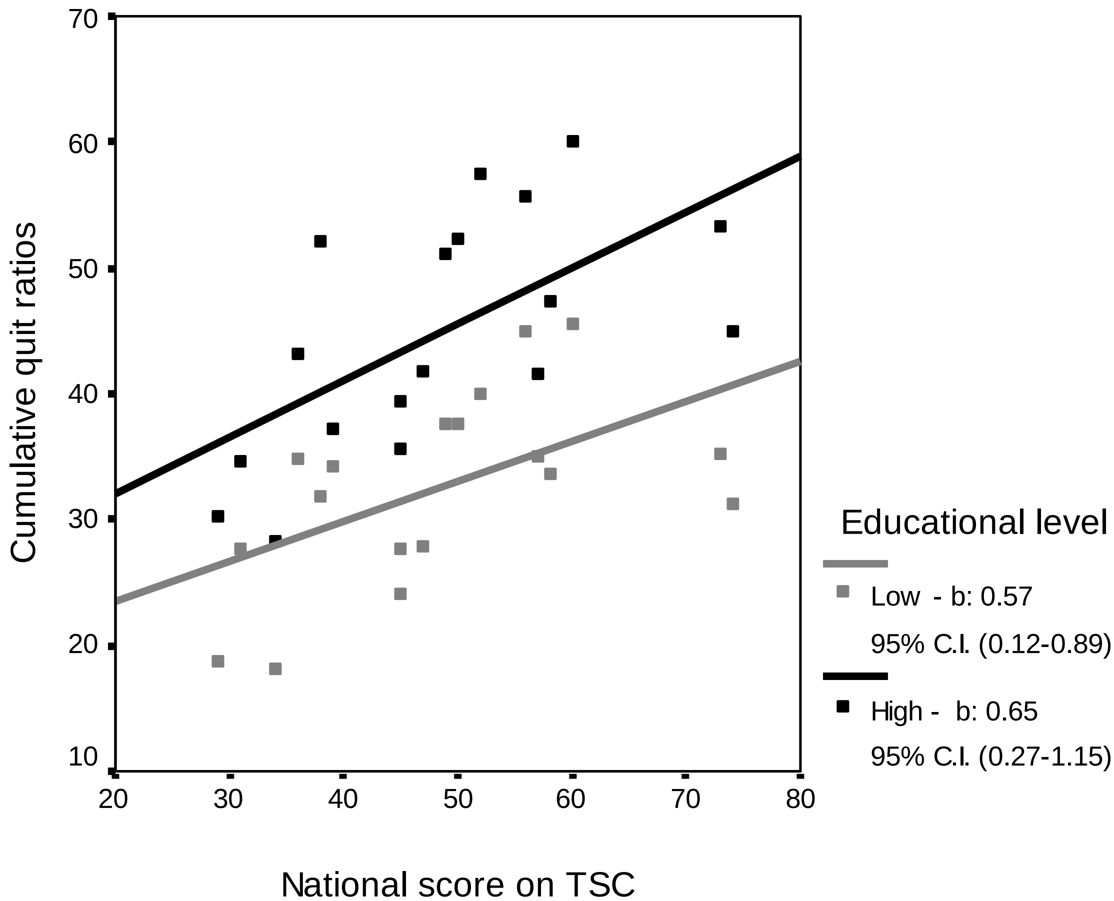
Table 1 Tobacco control policies in Europe

Country	**TCS**	**Country**	**TCS**	**Country**	**TCS**
Finland	58	Sweden	60	Denmark	45
England	73	Ireland	74	Netherlands	52
Belgium	50	Germany	36	France	56
Italy	57	Spain	31	Portugal	39
Slovakia	49	Hungary	47	Czech Republic	38
Lithuania	34	Latvia	29	Estonia	45
TCS: Tobacco Control Scale: 0 = minimal; 100 = full implementation					

Tobacco control policies vary from 29 in Latvia to over 70 in England and Ireland. Most profit can be made by the Baltic States, Spain, Germany the Czech Republic and Portugal, but also Denmark, Hungary and Slovakia have TCS levels below 50. On the other hand, even in countries with high levels of tobacco control policy implementation, like England and Ireland, there seems to be room for improvement.

Another important variable is education. If we look at smoking cessation rates of high and low educated persons, in relationship to the intensity of tobacco control policies, we may conclude that for both lower as well as higher educated persons there is a positive relationship between tobacco control policies and smoking cessation rates. Higher educated persons, however, benefit more of tobacco control policies than lower educated persons (see Figure 1).

Figure 1 Relationship between tobacco control policies and smoking cessation rates



Taking into account this general background, we formulated the following key questions for tobacco control:

1. What would future trends in smoking prevalence and smoking-related mortality and morbidity be if no further action were to be undertaken?
2. How would these trends be modified if tobacco control measures were to be fully implemented?
3. Do future trends and policy effects differ according to gender or socio-economic group (defined by different levels of educational attainment)?

There is a large literature on the effects of tobacco control policies on mortality and morbidity. Previous health models with smoking as risk factor showed that mortality and morbidity/disease risks are dependent on smoking status. These studies, however, do not model smoking prevalence. Alternatively, multi-state models of smoking model smoking prevalence as a function of smoking initiation and smoking cessation rates, but so far these studies are only carried out for a limited number of countries and the data used are often not representative for national populations. The added value of the MicMac model is that we can model smoking prevalence in relationship to smoking initiation and cessation in such a way that the analyses can be embedded in national population projections for all different European countries. Another advantage is that a distinction can be made between different sub-populations, for instance we can model effects on socio-economic inequalities in health.

The main objective for this case study is to estimate the potential effects of full implementation of smoking cessation policies on smoking prevalence and on mortality and disability in Italy.

2.2 The MicMac model

The MicMac model follows a life course approach. Instead of forecasting numbers of people it projects characteristics of people over their life courses. A life course is defined as a number of states and events. Each event implies a person enters a new state. Whether or not a person experiences an event, is determined by transition rates. MicMac consists of two modules: a microsimulation module (Mic) and a macrosimulation module (Mac). In this case study we use the MicMac microsimulation module with data for Italy.

2.2.1 The state space

As in the MicMac case study on health we focus on policy effects on future trends in smoking-related morbidity and mortality by gender and socio-economic status, apart from age and gender, we include the following variables in the study: 1) health status, 2) smoking status, and 3) educational attainment (as proxy for socio-economic group). Table 2 gives an overview of all distinguished variables and categories. For disability status we distinguish disabled persons from non-disabled persons. We used disability as the key health measure, because of high relevance of disability and functional impairments to the health and health care utilization of elderly people. For smoking status we distinguish three levels: never smokers, current smokers and ever smokers. Finally, we distinguish three levels of education: Low education refers to reached levels of primary education or less, up to lower secondary education (ISCED0-ISCED2); medium education refers to higher secondary education (ISCED3 and ISCED4), while high education refers to reached levels of tertiary education (ISCED 5 and ISCED6).

The main data source we used is the European Community Household Panel (ECHP), managed by Eurostat. The ECHP is a longitudinal, multi-subject survey covering many aspects of daily life, particularly employment and income, but also education, household composition and health. From 1995 (wave 2) onwards, ECHP utilized the same questions on disability in each wave. The first question was: "Do you have any chronic physical or mental health problem, illness or disability?" If the answer was yes, a subsequent question was asked: "Are you hampered in your daily activities by this physical or mental health problem, illness or disability?" Two possible answers distinguished between two severity degrees: “Yes, to some extent” or “Yes, severely”. In the current case study disability refers to “severely hampered in daily activities”.

Information on smoking was available only from the 5th wave (1998). Throughout the study period, respondents were classified according to smoking status as observed during this wave. This approach was taken in order to utilize as much as possible the longitudinal nature of the data, in which the cause (i.e. exposure to smoking) should be measured well before the consequence (i.e. health transition).

The original classification of smoking status encompassed five categories. We compressed these into three classes: (1) Current daily smokers, (2) Former daily smokers, and (3) Never daily smokers. The latter included those who smoke occasionally or who used to smoke occasionally. The number of occasional smokers was too small to study as a separate category. They were combined with never smokers because evidence from preliminary analysis indicated, as does the general epidemiology literature, that occasional smoking increases health risks to only a modest extent.

Table 2 The MicMac state space for the case study on health

Variables	Label	Categories
Health status	nD	Non disabled
	Di	Disabled
Smoking status	nS	Never
	cS	Current
	eS	Ever
Educational attainment	L	Lower secondary education or less (ISCED02)
	M	Higher secondary eduction (ISCED34)
	H	Tertiary education (ISCED56)

Table 3 lists all possible states of the case study. In total these amount to 12 different states (for males and females, respectively).

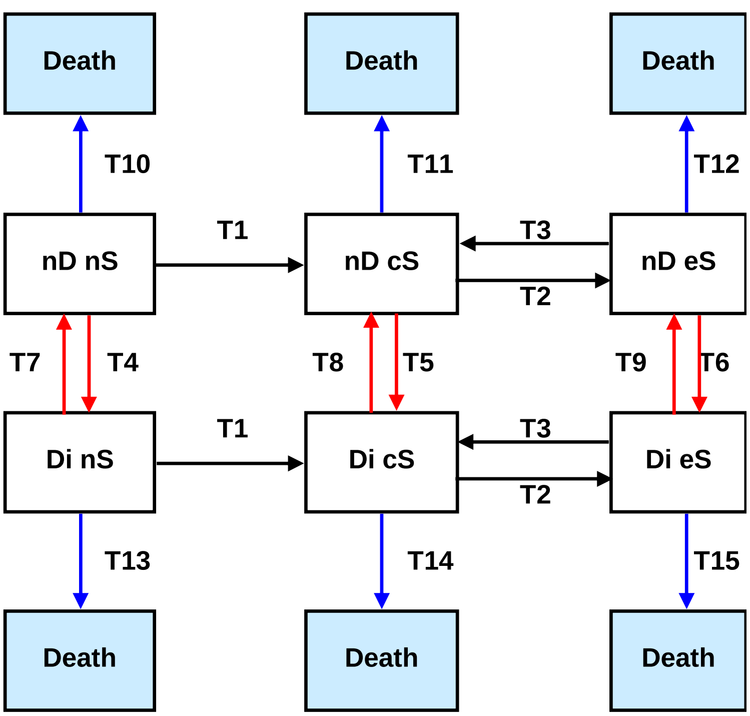
Table 3 All states included in the case study on health

State	Educational attainment	Smoking status	Health status
L nS nD	Lower education	never Smoker	non Disabled
L cS nD	Lower education	current Smoker	non Disabled
L eS nD	Lower education	ever Smoker	non Disabled
M nS nD	Medium education	never Smoker	non Disabled
M cS nD	Medium education	current Smoker	non Disabled
M eS nD	Medium education	ever Smoker	non Disabled
H nS nD	Higher education	never Smoker	non Disabled

H cS nD	Higher education	current Smoker	non Disabled
H eS nD	Higher education	ever Smoker	non Disabled
L nS D	Lower education	never Smoker	Disabled
L cS D	Lower education	current Smoker	Disabled
L eS D	Lower education	ever Smoker	Disabled
M nS D	Medium education	never Smoker	Disabled
M cS D	Medium education	current Smoker	Disabled
M eS D	Medium education	ever Smoker	Disabled
H nS D	Higher education	never Smoker	Disabled
H cS D	Higher education	current Smoker	Disabled
H eS D	Higher education	ever Smoker	Disabled

Figure 2 sketches the incidence, recovery and mortality transitions with covariate smoking. The white box entitled ‘nD nS’ for instance refers to ‘non Disabled – never Smoker’. In this figure we left out education. Education can be interpreted as an additional layer to the diagram with health transitions. The white box ‘nD nS’ can be split up in three boxes, one for each category of education: ‘nD sS L’ for levels of educational attainment up to ISCED02, ‘nD nS M’ for higher secondary education (ISCED34), and ‘nD nS H’ for tertiary education (ISCED56).

Figure 2 State space diagram: states and transitions



The arrows in Figure 2 represent the transitions. The black (horizontal) arrows T1 to T3 refer to transitions between different categories of smoking status. T1 for instance refers to the transition from ‘never smoker’ to ‘current smoker’. These transitions are assumed independent of disability status. The red arrows T4 to T9 (vertical arrows between ‘non disabled’ and ‘disabled’), refer to incidence and recovery rates, while the blue arrows T10 to T15 refer to death rates.

2.2.2 Transition rates

We used the ECHP data to derive estimates of age profiles of the incidence rates, recovery rates and related mortality rates (of disabled and non-disabled people, respectively). The estimates were prepared for male and female populations at large, and for subgroups of the populations defined in terms of smoking habits and final level of educational attainment. At first estimates were prepared for Europe as a whole, after which rescaling factors were calculated to derive estimates for Italy (see Majer, Nusselder and Kunst, 2008).

Apart from the disability-related transitions, smoking initiation and cessation rates were estimated from national Italian retrospective surveys (see Frederico *et al*., 2007). For education we used transition probabilities for Italy based on Labour Force Survey data for the period 2004-2007, calculated by VID (see Goujon, 2008).

All age profiles are sketched in Figures 3-21.

Figures 3 to 6 display the incidence rates for males and females, respectively. The incidence rates for daily (current) smokers and past smokers are almost identical, while the incidence rates for never smokers are substantially lower. People with low levels of education have higher risks to become disabled. Similar patterns are found for males and females, although incidence rates for females are generally higher than for males. The similar rates for current smokers and past smokers might be explained by a strong selection bias in past daily smokers, namely that these persons quitted smoking because of health problems.

The recovery rates are depicted in Figures 7 to 10. In this case the rates are higher for never smokers than for daily and past smokers. For daily and past smokers the prospect to recover from disability is more or less similar. High educated persons have almost identical recovery rates compared to people with medium levels of education, while the prospects to recover are substantially lower for persons with low levels of education.

Figures 11 to 14 show death rates for non disabled males and females. Highest death rates are found for daily smokers, while the lowest are found for past smokers, although the differences between the rates for past smokers and never smokers are only very small. Hardly any difference was found between the different levels of education. For disabled persons, on the other hand, death rates differed between level of education, with lowest death rates for low educated persons and highest rates for persons with a medium level education. In this case, however, there is hardly any difference in smoking states (see Figures 11 to 14). Death rates for females are generally lower than for males.

Figures 15 to 18 show death rates for disabled males and females. For disabled persons we see only differences between males (higher death rates) and females. There are hardly any differences between level of education or whether persons are never, daily or past smokers.

To sum up, the age profiles lead to the following conclusions:

- The risk for females to become disabled is higher than for males, but females also have better prospects to recover than males, especially in the ages between of 15 and 35.
- Mortality rates for men are higher than for women, notwithstanding whether they are non-disabled or disabled.
- Similar effects for males and females are found for education and smoking behaviour: never smokers have lower risks to become disabled or to die, and better prospect to recover compared to daily and past smokers.
- The rates did not show an effect of quitting smoking on incidence or recovery; reduced mortality rates for persons that quit smoking were only found for those persons that were non-disabled.
- The small differences between the daily and past smokers might be explained by a strong selection bias.

Figure 19 shows the transitions from never smoker to daily smoker and from daily smoker to past smoker. Here we only distinguish between two levels of educational attainment: low (ISCED02) versus high (ISCED36/56). In principle, smoking initiation is higher for males than for females and for lower than for higher educated people. Quit rates are higher for females than for males up to age 40 and higher for high educated persons compared to low educated persons up to age 60. From age 40 and 60, respectively, this turns the other way round. For past smokers, we assumed that they will not start smoking again, therefore we did not include relapse rates.

For this case study we run two scenarios. The first scenario is the baseline scenario in which all transition rates remain constant over time (i.e. similar age patterns for each period). The assumed Tobacco Control Scale for this scenario is 58. The second scenario is an intervention scenario, where we assume the smoking cessation rates to increase as a result of full implementation of tobacco control policies (TCS=100) in 2005 and to remain stable thereafter. The effect estimate (per one unit increase in TCS) is 0.57 for low education and 0.65 for medium and high education. The resulted (absolute) increase in quit rates is 0.0239 for low educated persons and 0.0273 for medium and high educated persons. We assume similar effects for males and females. Figure 20 shows the smoking transition rates for the intervention scenario.

Figure 21, finally shows the transitions into higher levels of education. The transition from low to medium education is highly peaked and takes place within the age interval between age 18 and 24. The transition to high education is more spread between age 20 and 30.

3 Results

At first we show the future trends in the distribution of the population by smoking status and disability status under the baseline scenario. Subsequently, we show similar figures under the intervention scenario. We focus on the distribution for cohort aged 30-39 at the start of the simulation.

From Figure 22 we learn that at the start of the simulation for the total cohort aged 30-39 about 60 per cent belongs to the group of never smokers. This percentage remains relatively stable until the cohort reaches the age of 60-69, after which it declines which is mainly related to the increasing number of deaths from the age of 60 onwards. As expected, lower percentages of never smokers are found for males compared to females (Figures 23 and 24) and for lower educated persons compared to higher educated persons (Figures 25 and 26). At the end of the simulation period, about 40 per cent of the total cohort has died. While only about half of the men survives, this applies to 70 per cent of the women. The share of the daily smokers decreases for men and women, as well as low and high educated persons to below ten per cent of the original population. The percentages of past smokers are higher among men than among women, and among low educated persons than among high educated persons.

The percentages disabled persons at the start of the simulation period is rather low for all groups, and increases almost linearly until this cohort reaches the age of 70-79 (see Figures 27-31). Similar patterns are found for cohorts aged 40-49 and 50-59. For these cohorts the number of survivors sharply declines after they reached the age of 70-79 (see Figures 32 and 33).

Figures 34-45 show similar distributions under the intervention scenario. As a result of the intervention, the percentages of past smokers are higher, and that of daily smokers are lower compared to the baseline scenario (Figures 34-38). Given the small differences in incidence, recovery and death rates between past smokers and daily smokers, however, this has hardly any effect on the percentages of disabled and dead persons.

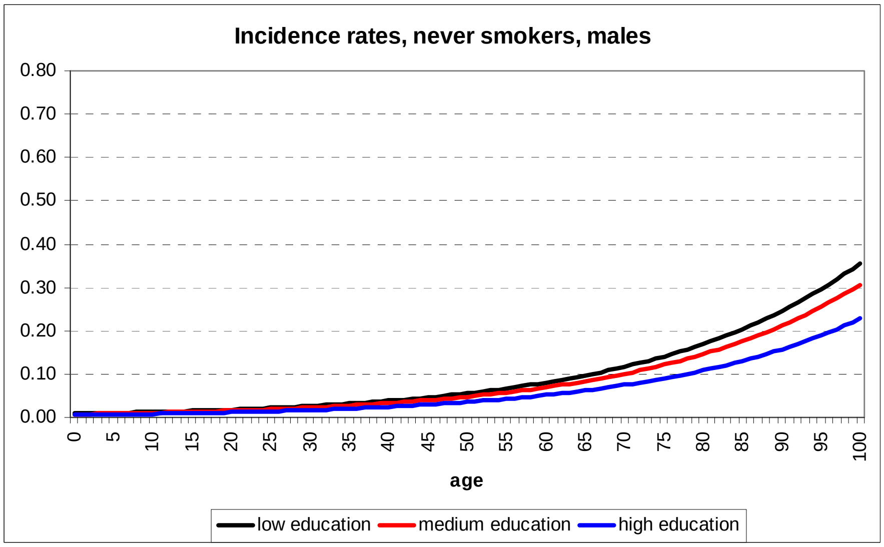
4 Discussion

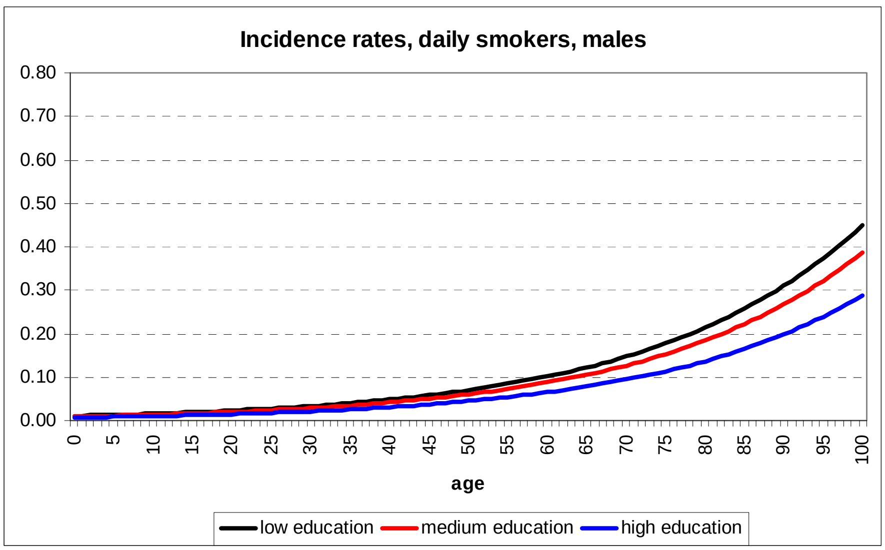
Although the potential effects of intervention policies on future smoking prevalence are substantial, the effects on mortality and disability seem to be small. One reason for these small differences may be that former smokers may have increased risks for disability incidence and mortality compared to never smokers. An increase in smoking cessation rates at higher ages (above 50 years) may be too late to have substantial health effects. Further research is needed to fully understand these findings.

In this case study we only investigated a baseline scenario and one intervention scenario with a few outcome variables. In further research we may study a broader range of tobacco control policies, for instance a more ambitious goal for smoking cessation as well as a reduction of smoking initiation rates among adolescents. Furthermore, we may have a look at a broader range of outcome variables, for instance the total number of deaths and disability avoided in the national population.

A final question is how can we utilize the information derived from the individual life courses? With MicMac we can generate information on duration in different states as well as information on the timing of events. Therefore we can study the duration of the state “smoking”, e.g. pack years smoked; the duration of disability, e.g. the distinction between short and long episodes of disability; the timing of disability, e.g. disability in midst of life versus disability preceding death; and survival free of disability up to the retirement age, i.e. 65 years or higher.

Figure 3   Incidence rates, males (1)





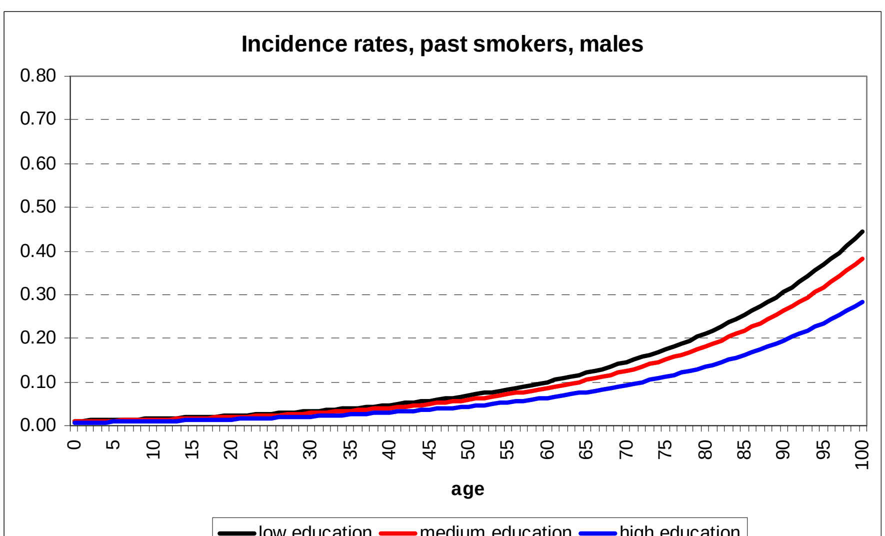
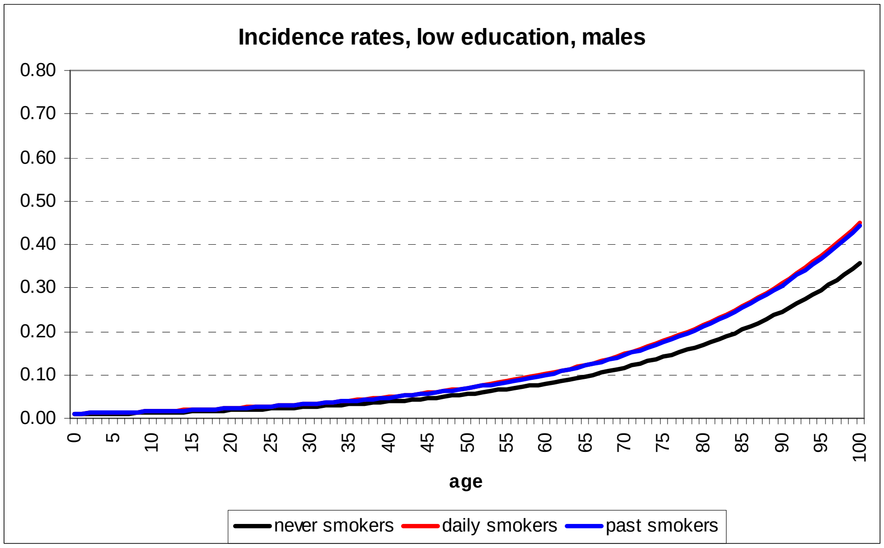
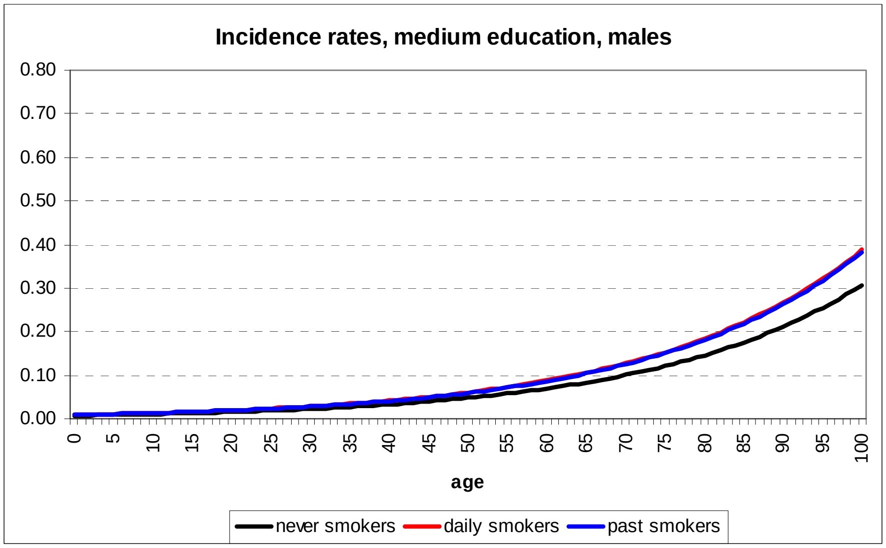


Figure 4   Incidence rates, males (2)





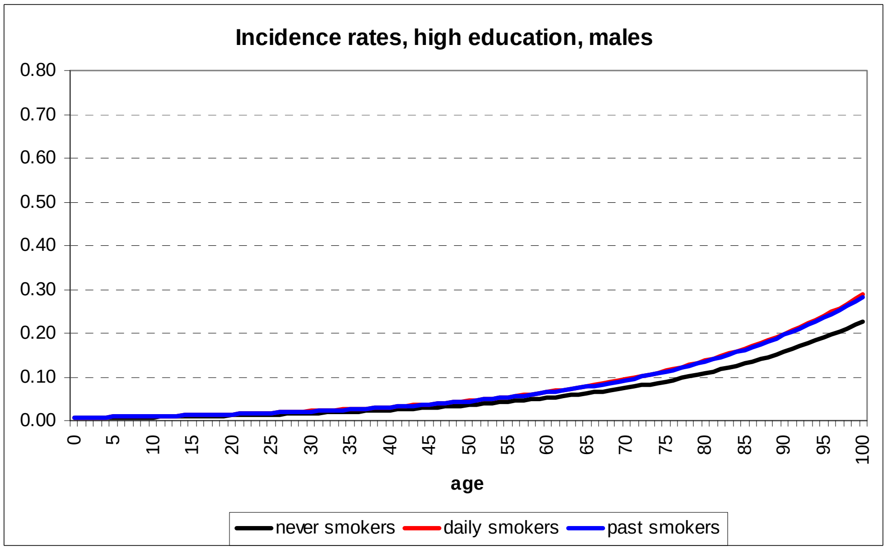
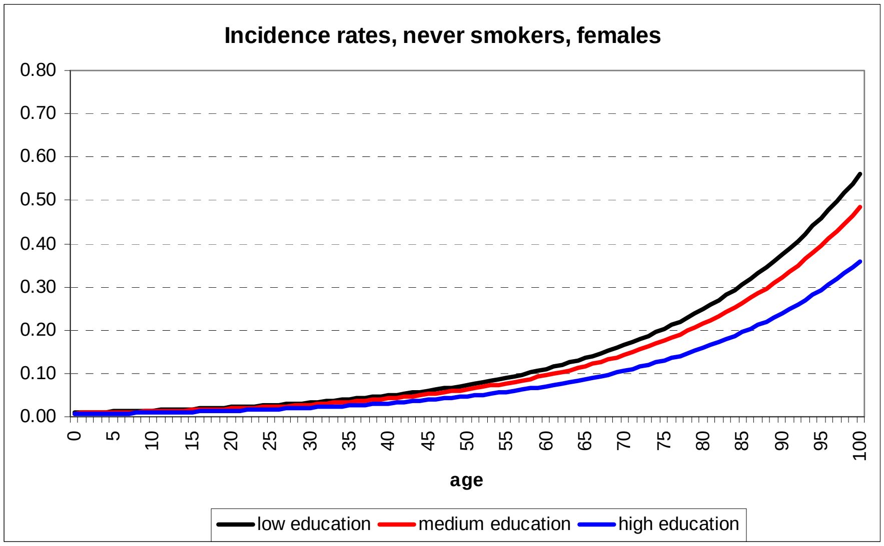
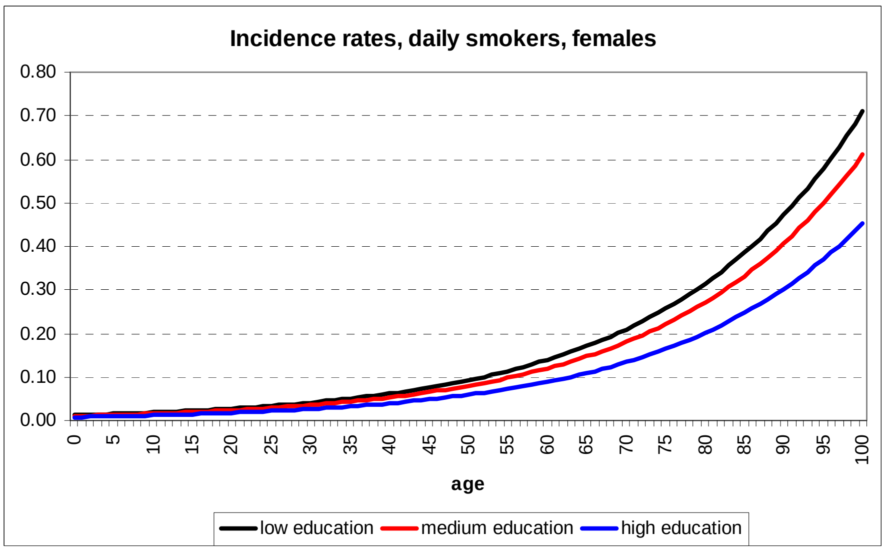


Figure 5 Incidence rates, females (1)





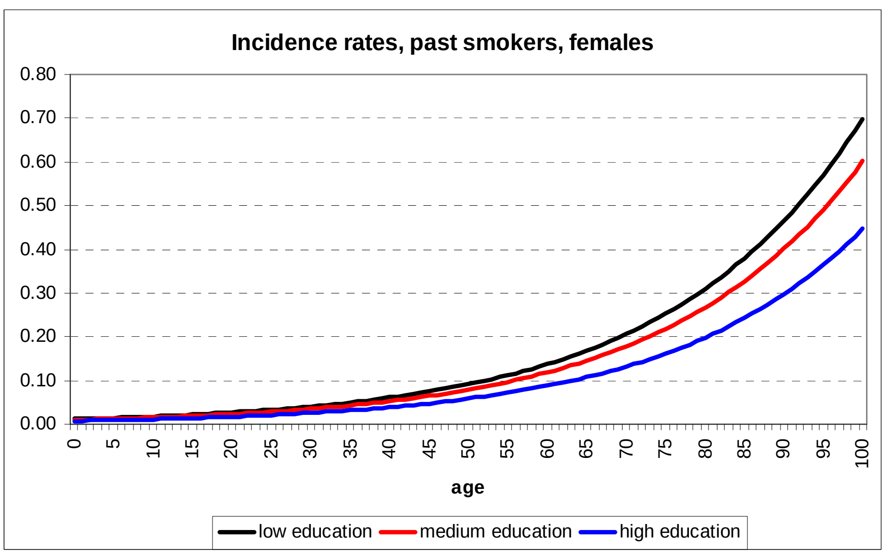
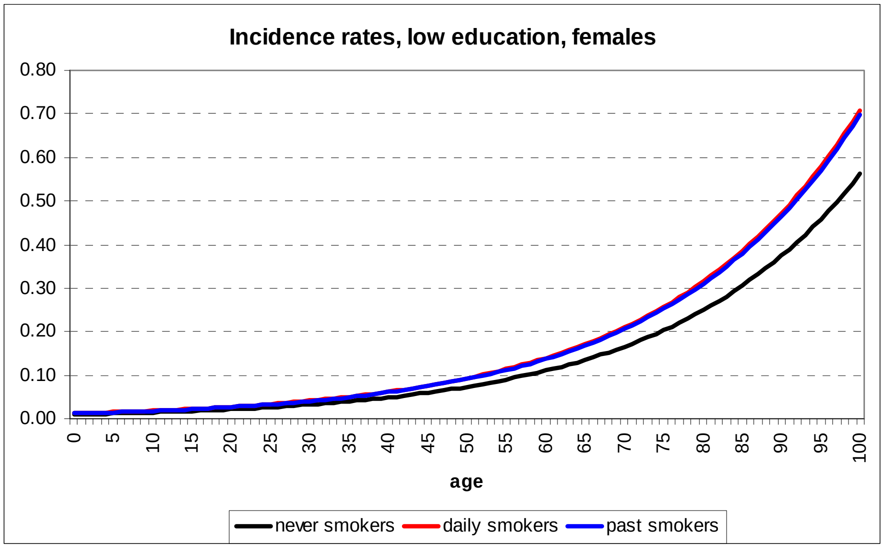
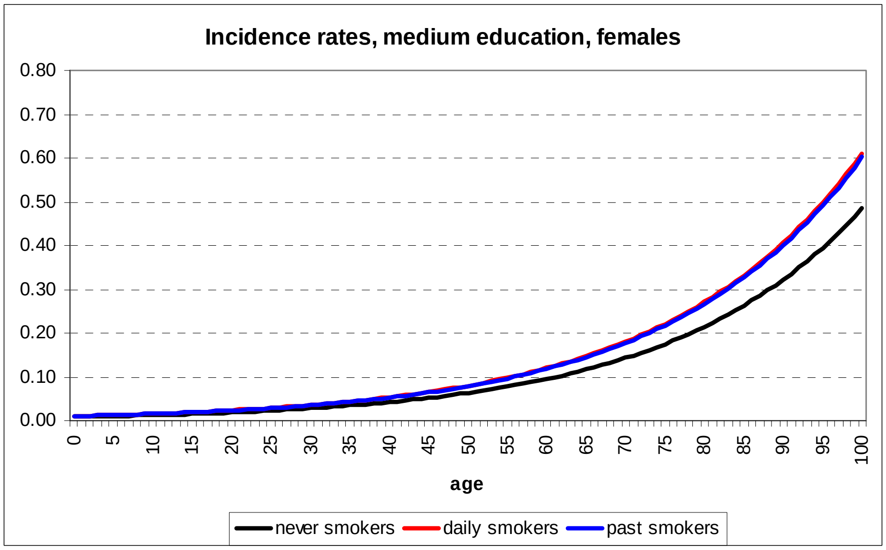


Figure 6   Incidence rates, females (2)





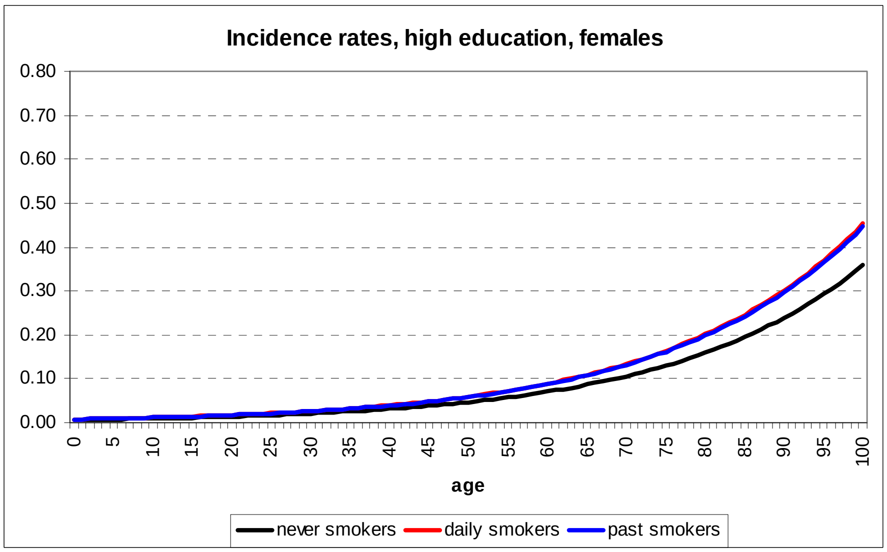
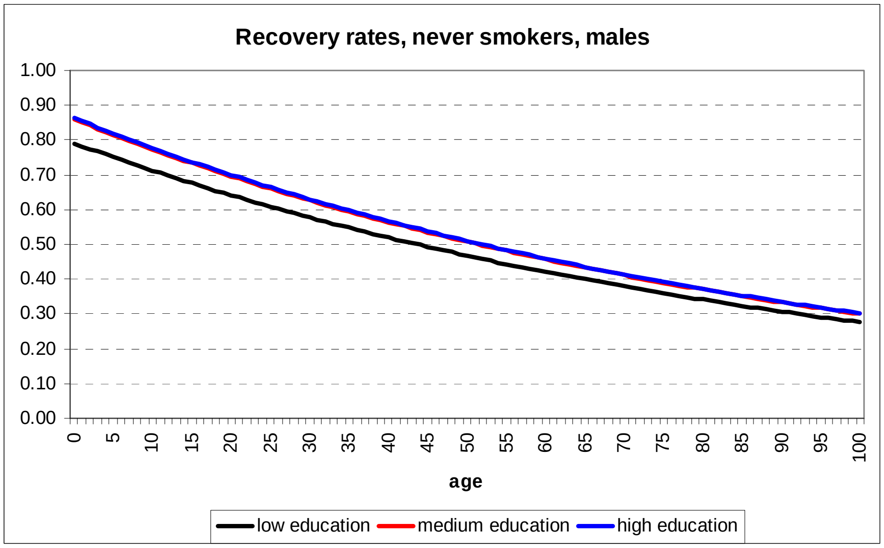
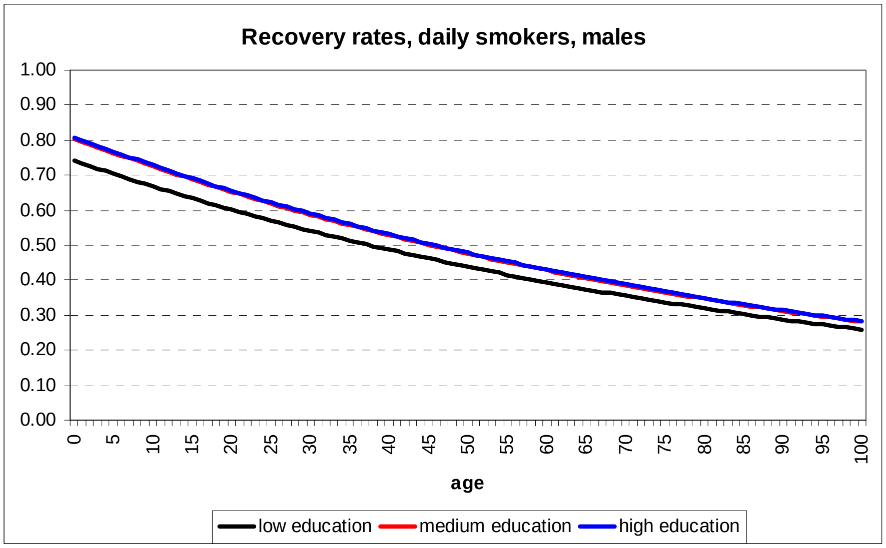


Figure 7   Recovery rates, males (1)





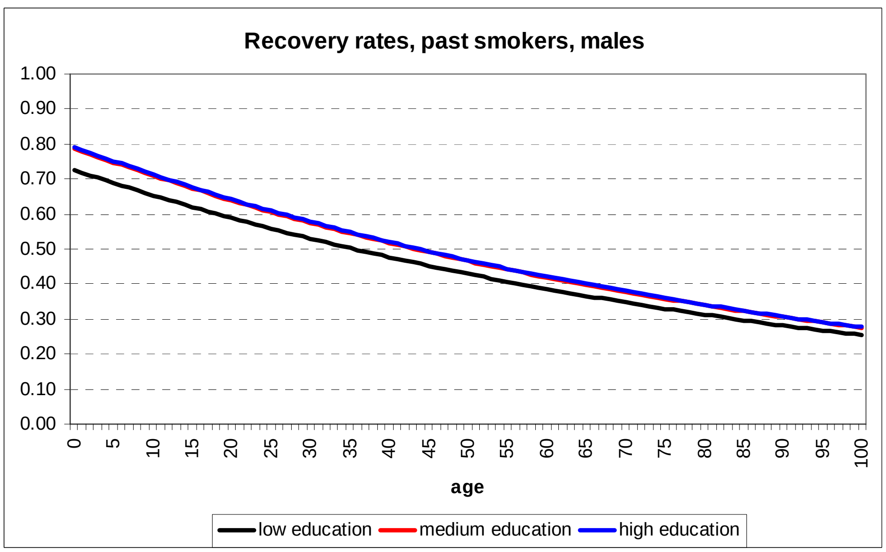
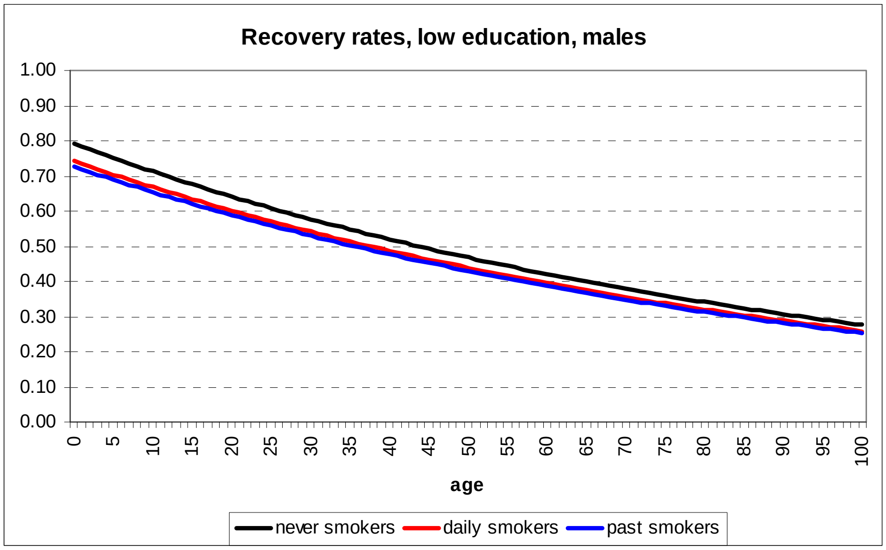
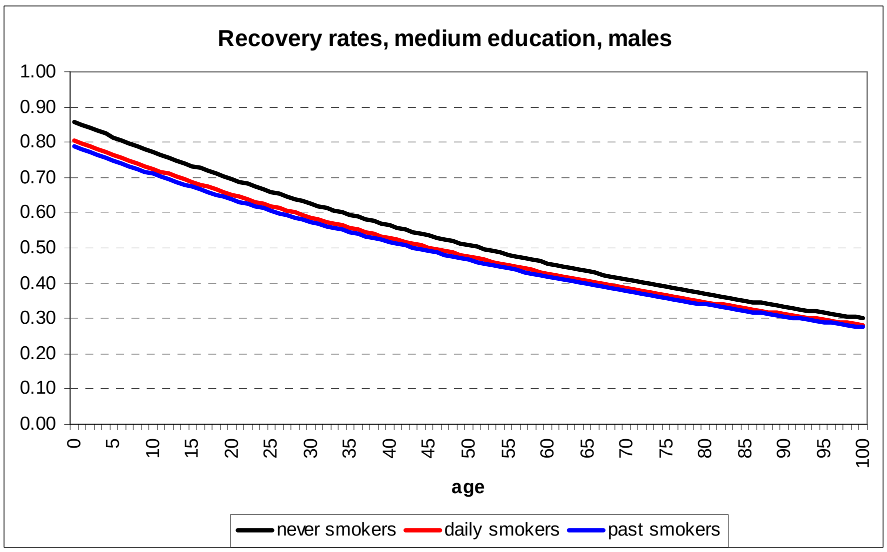


Figure 8 Recovery rates, males (2)





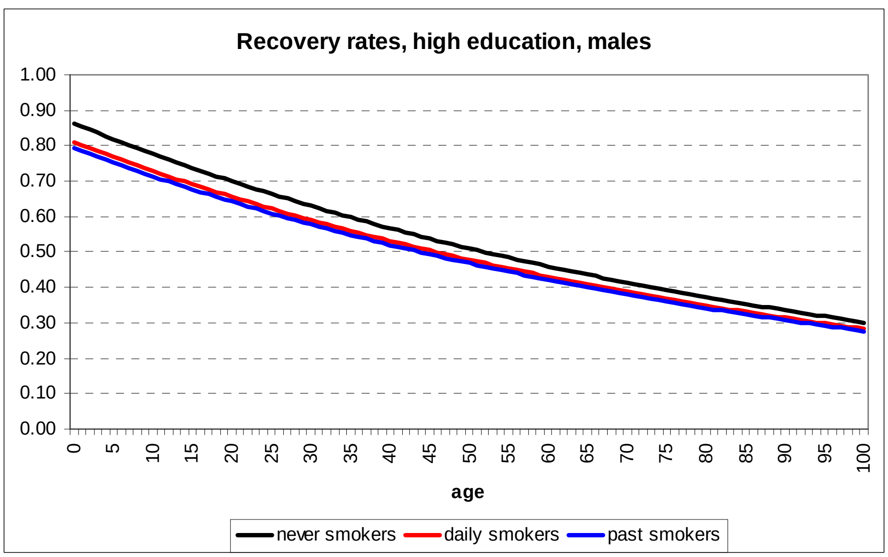


Figure 9   Recovery rates, females (1)

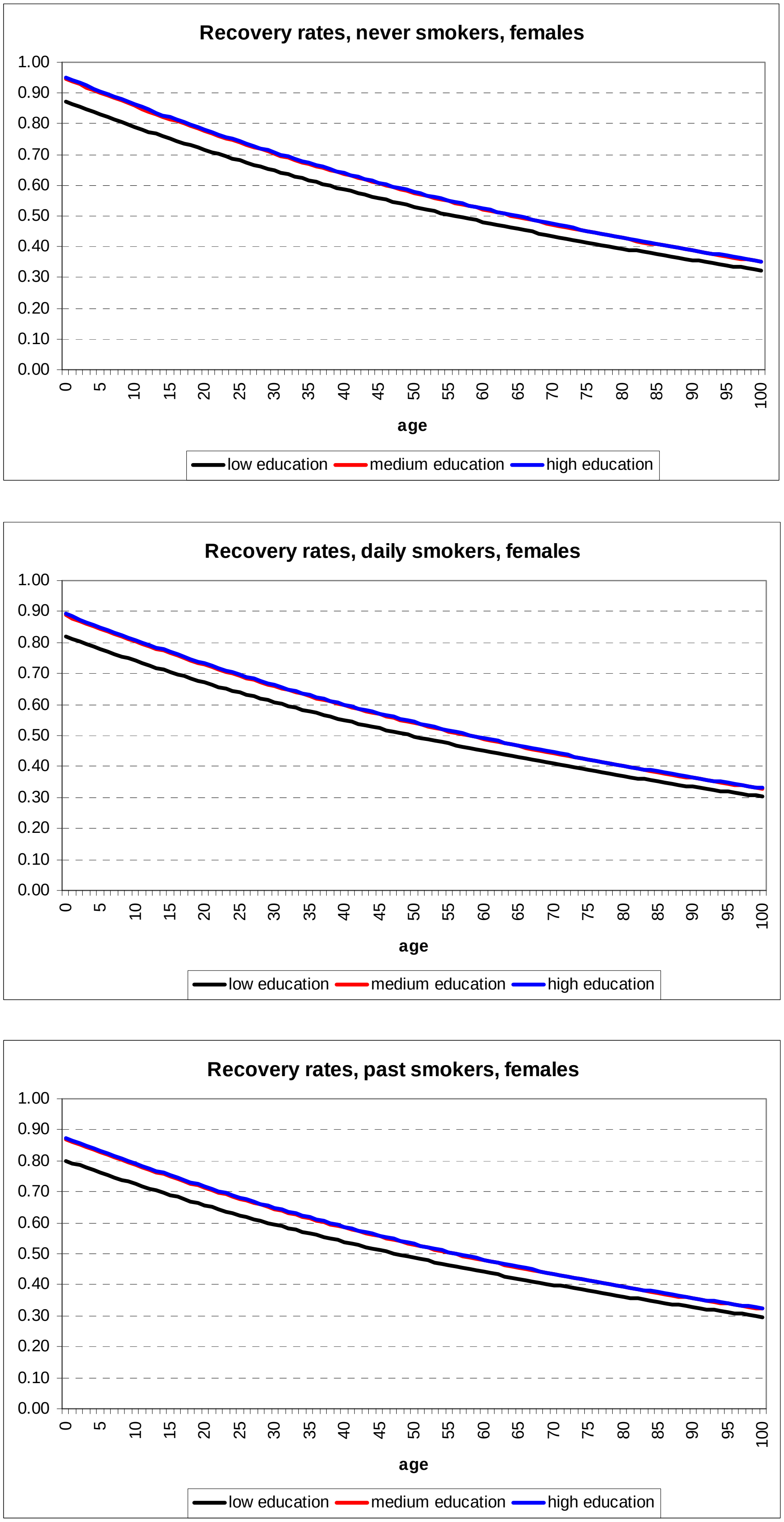
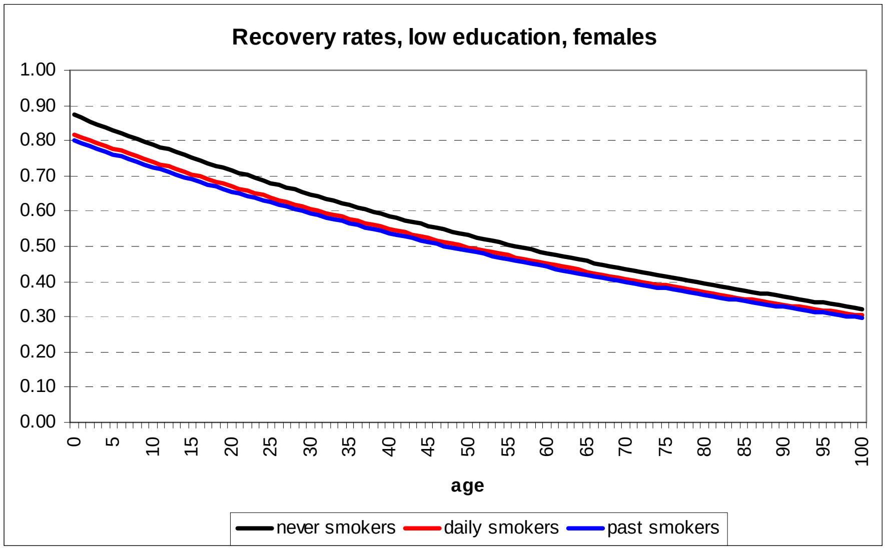
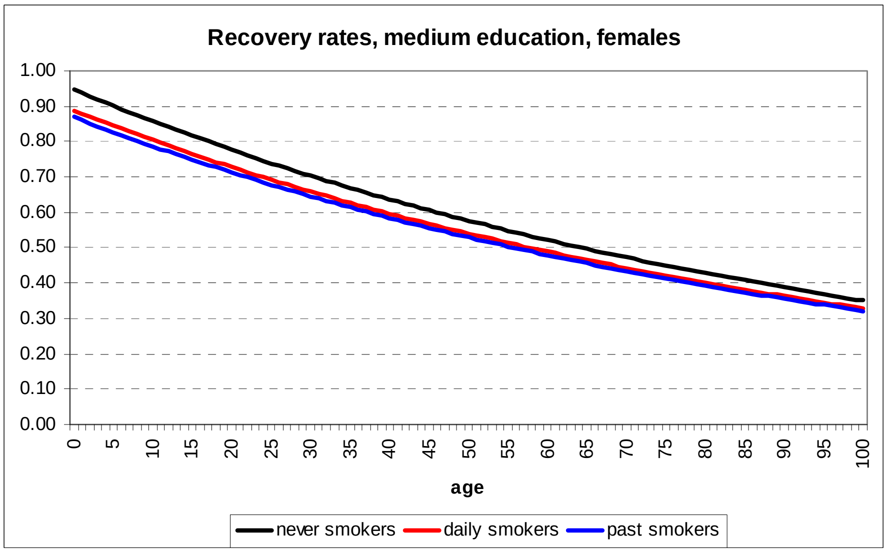


Figure 10 Recovery rates, females (2)





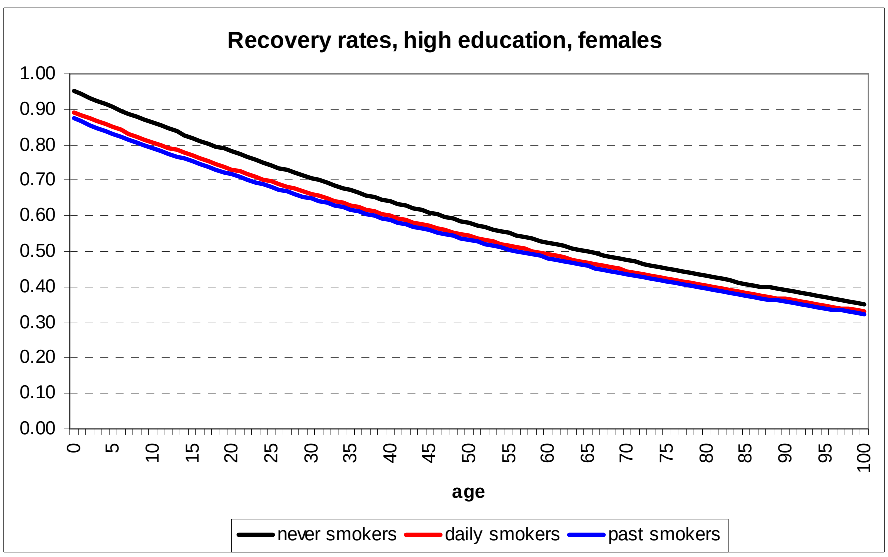
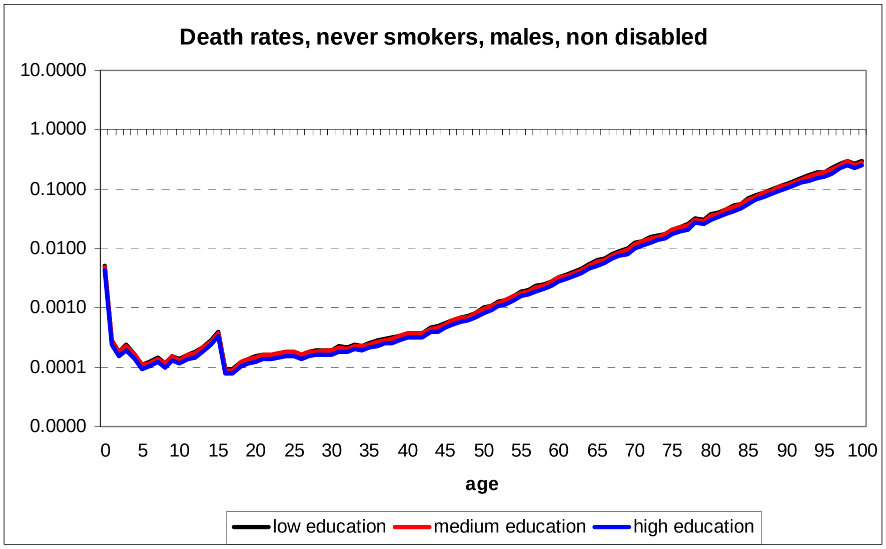
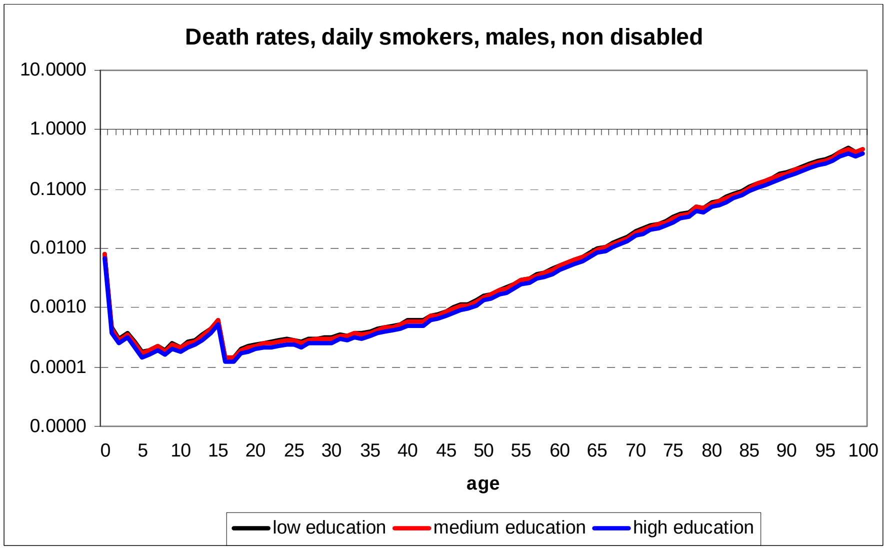


Figure 11 Death rates, males, non disabled (1)





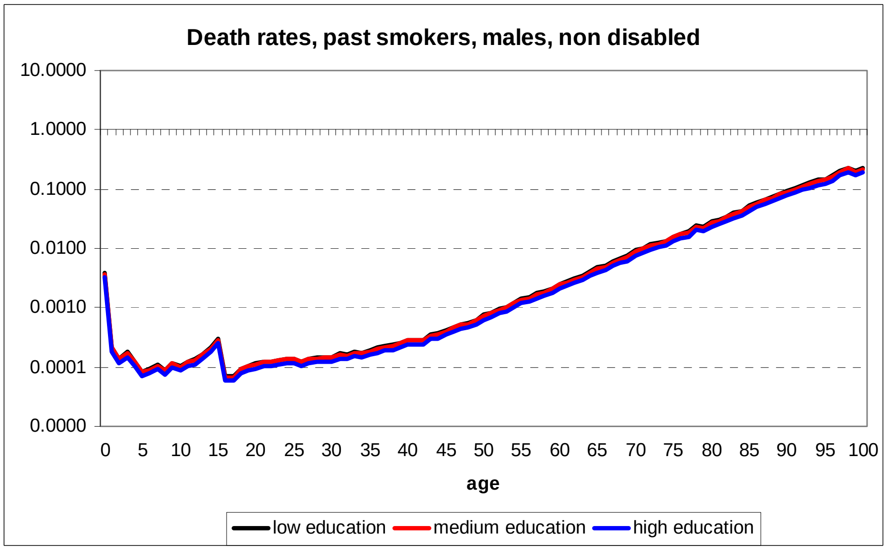
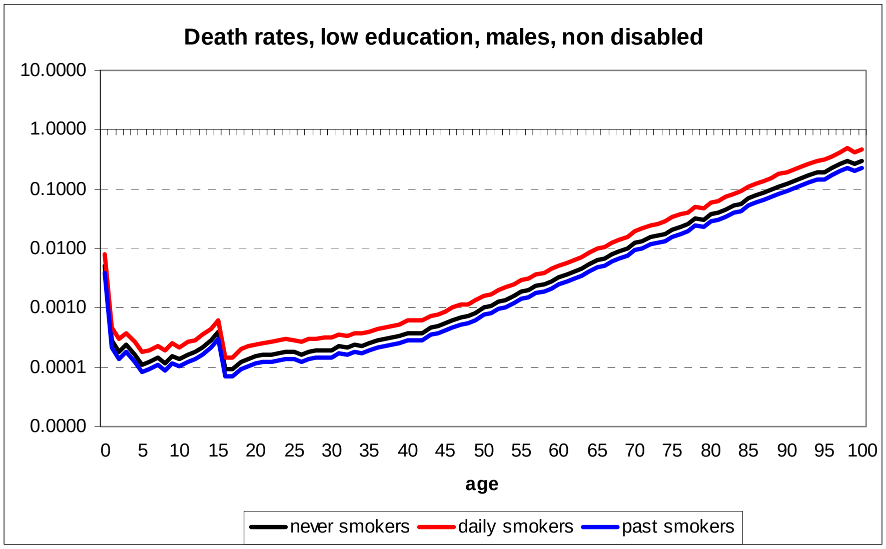
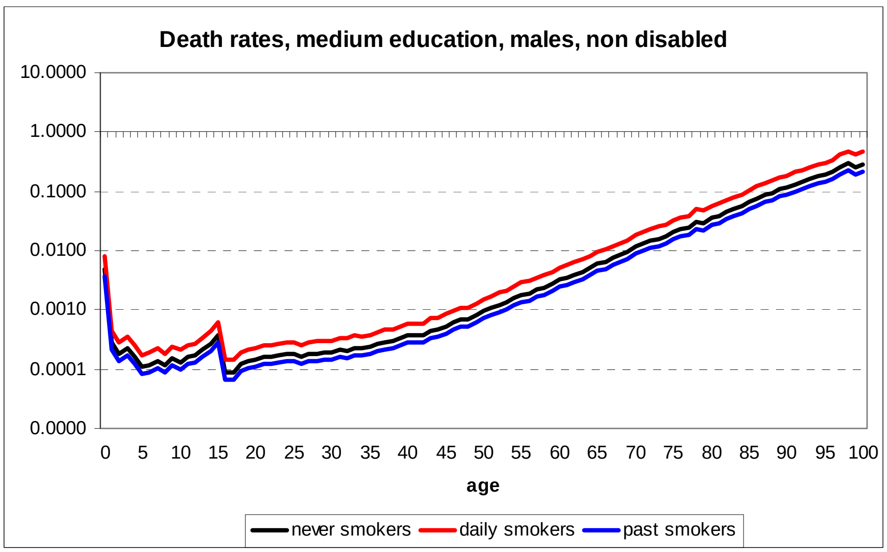


Figure 12 Death rates, males, non disabled (2)





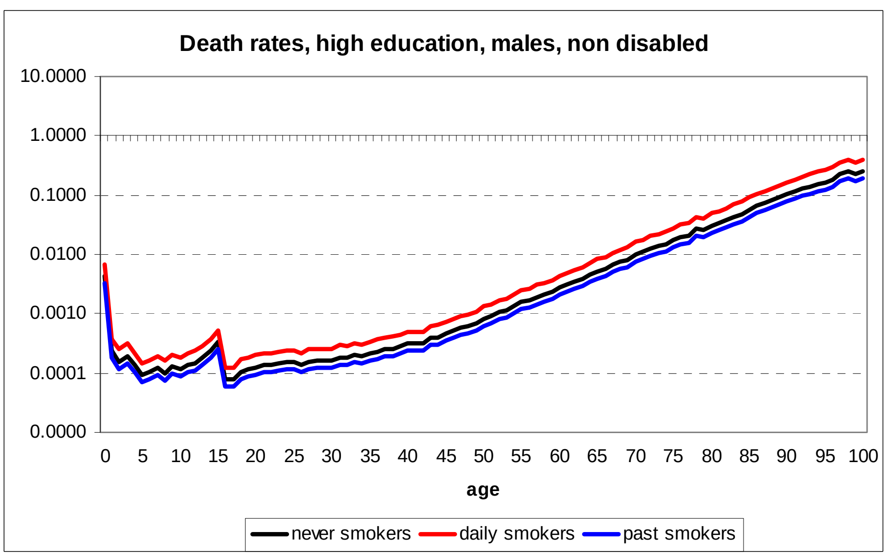
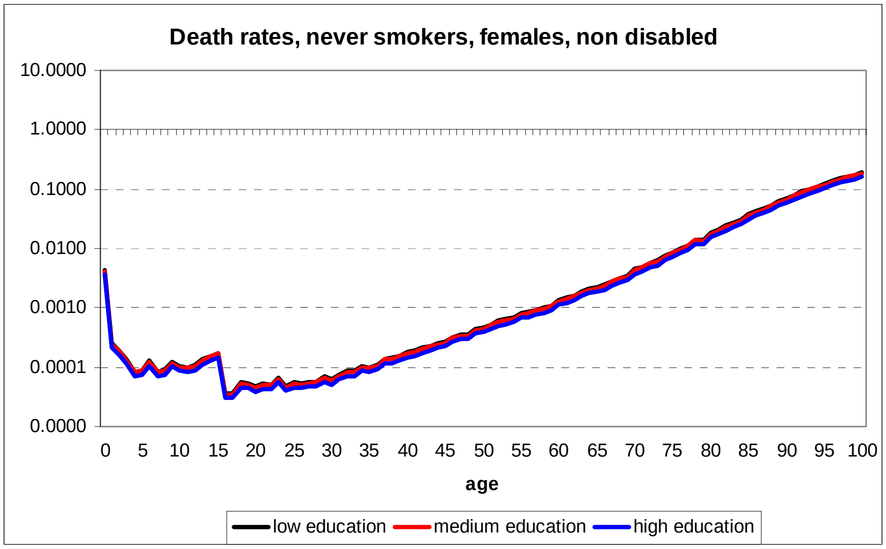
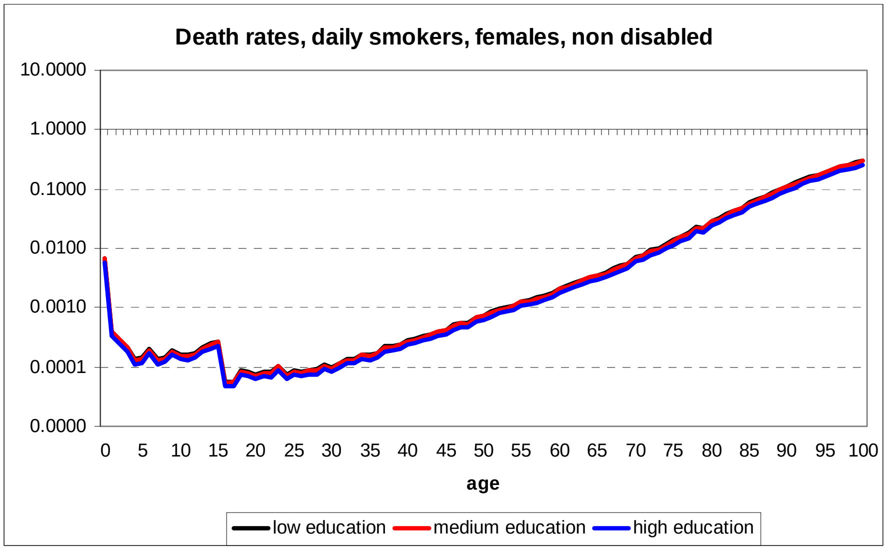


Figure 13 Death rates, females, non disabled (1)





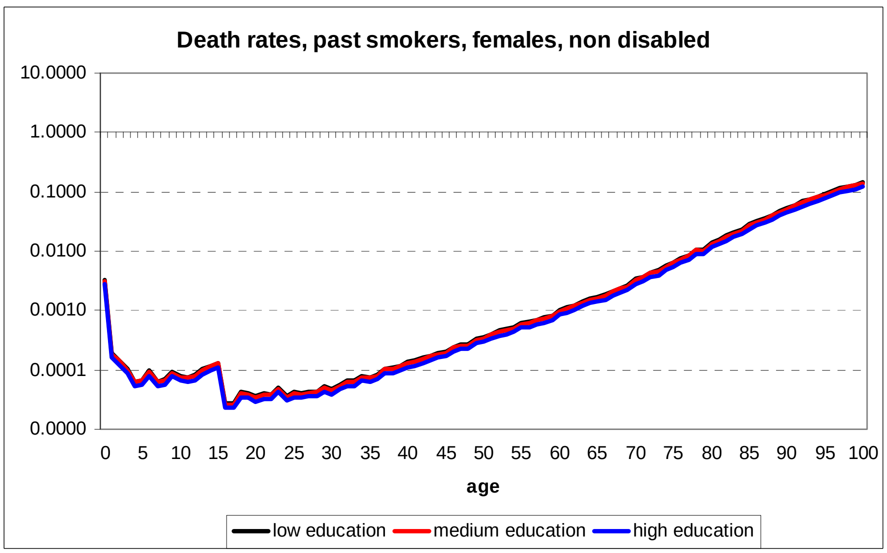
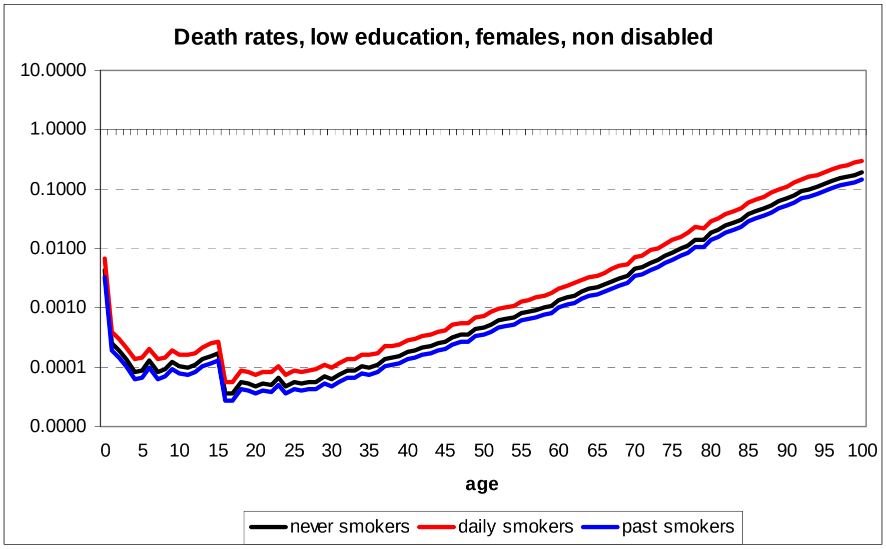
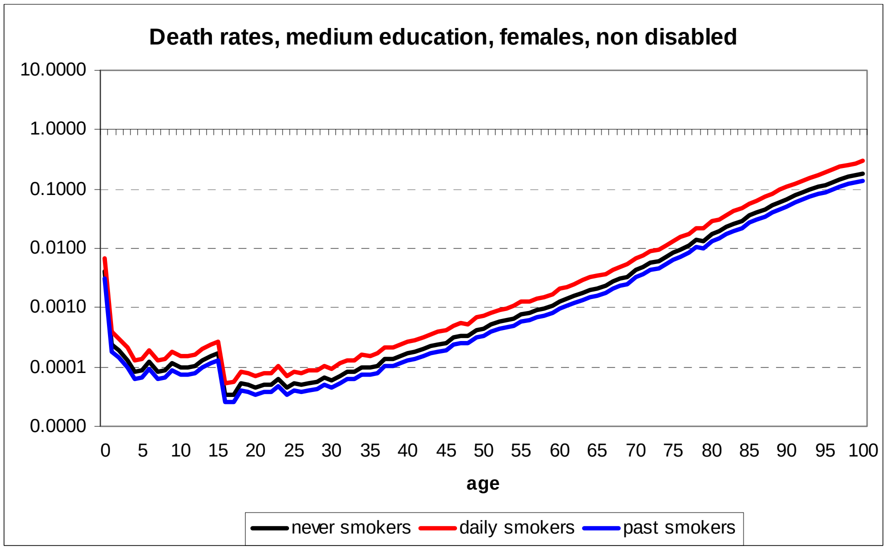


Figure 14 Death rates, females, non disabled (2)





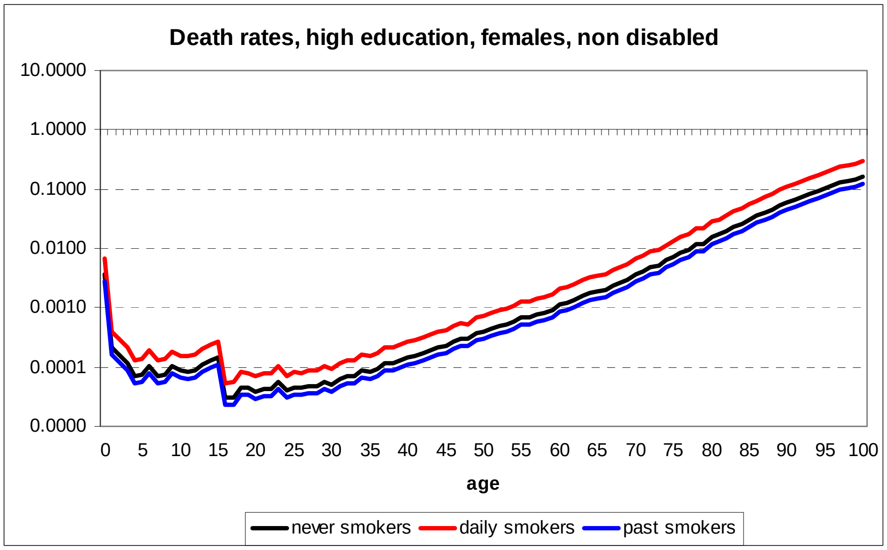
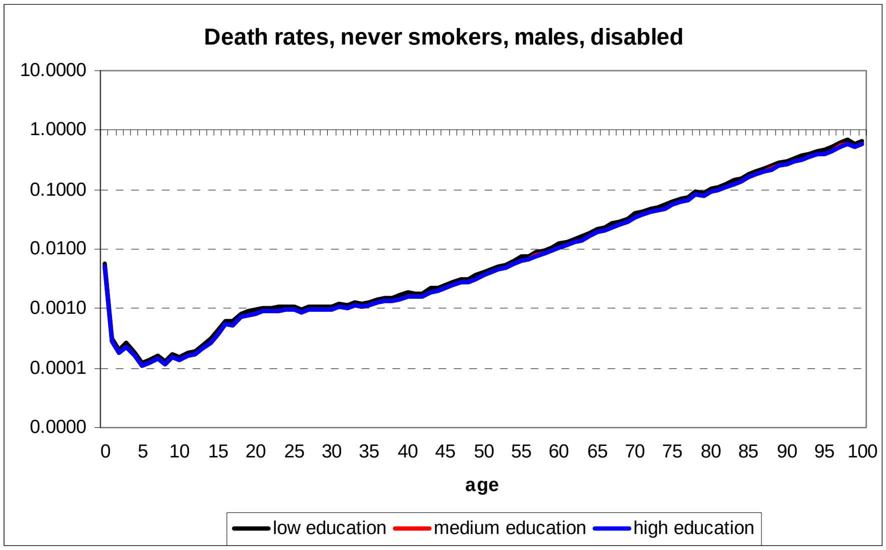
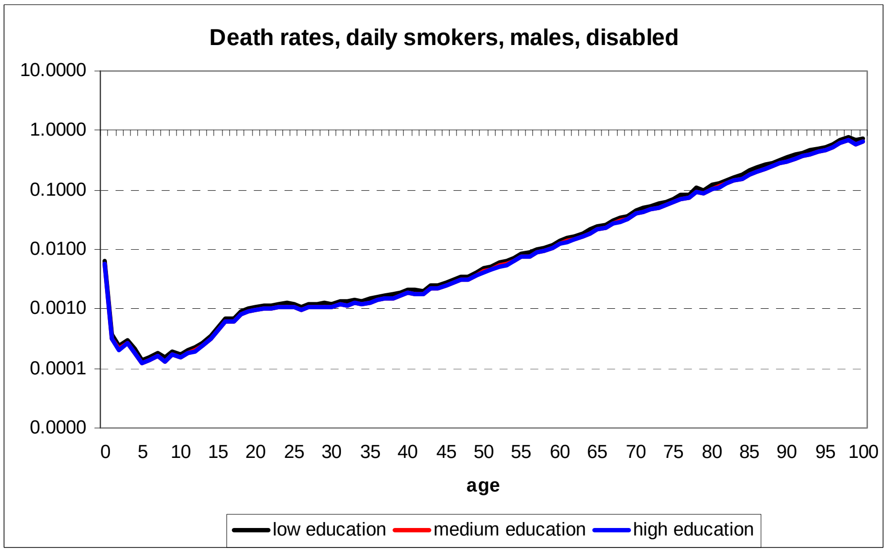


Figure 15 Death rates, males, disabled (1)





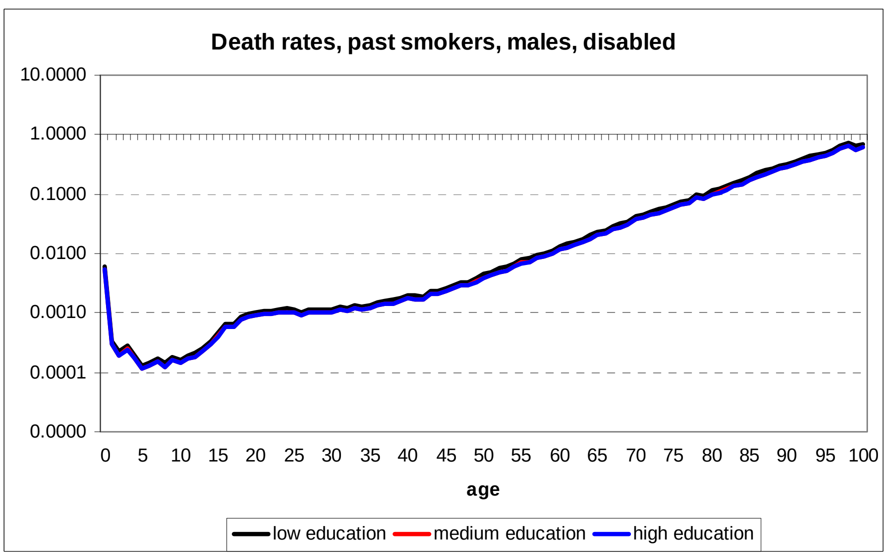
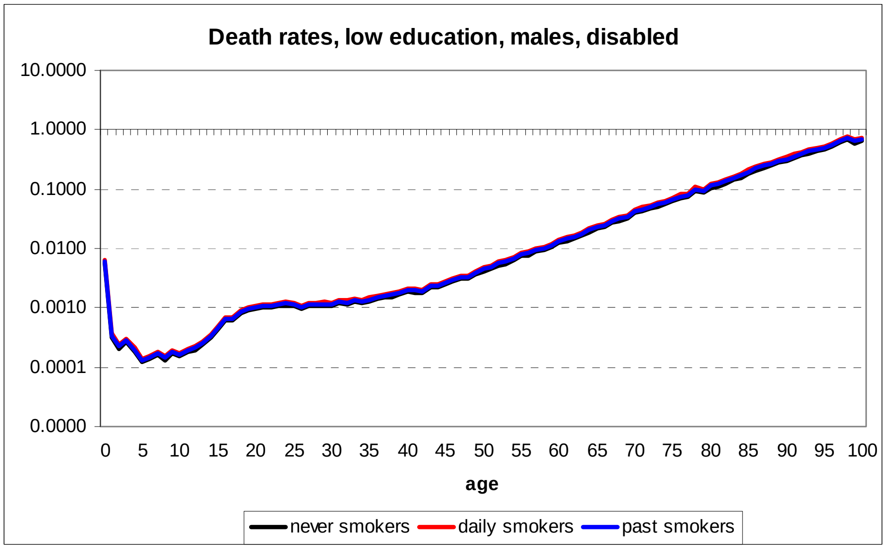
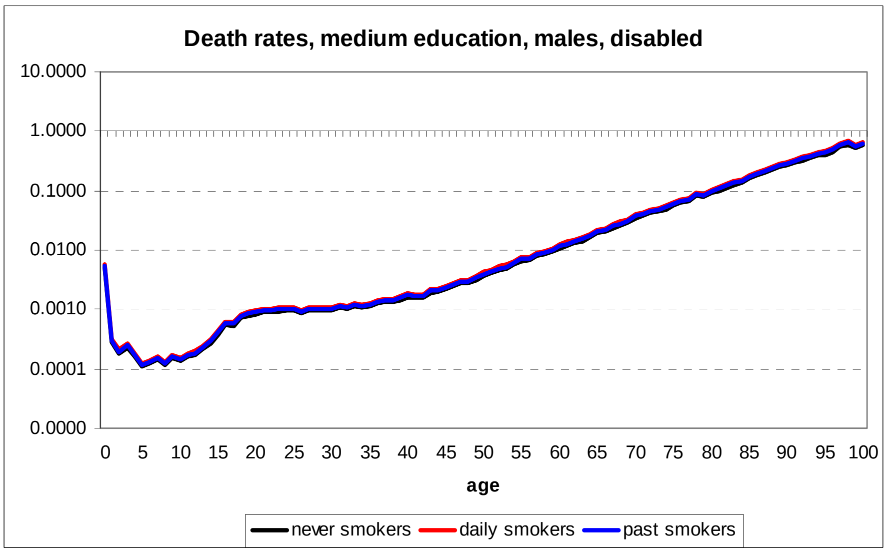


Figure 16 Death rates, males, disabled (2)





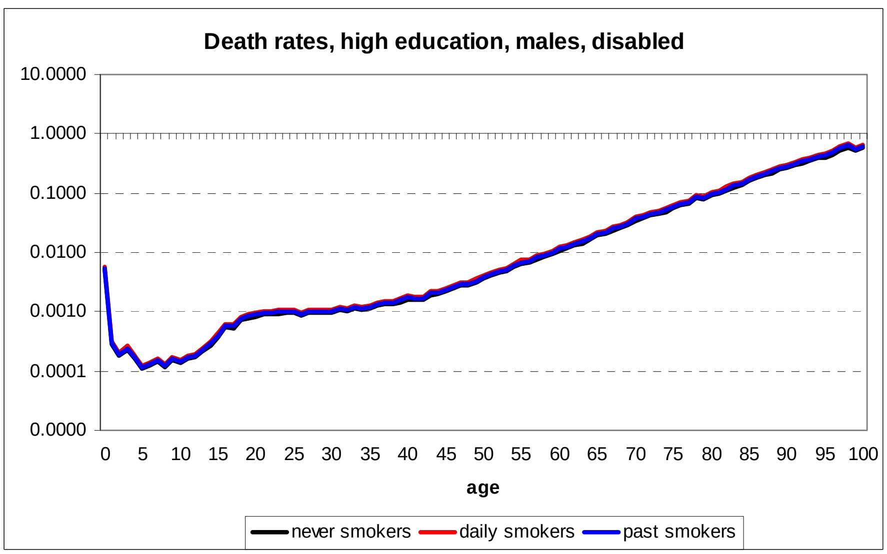
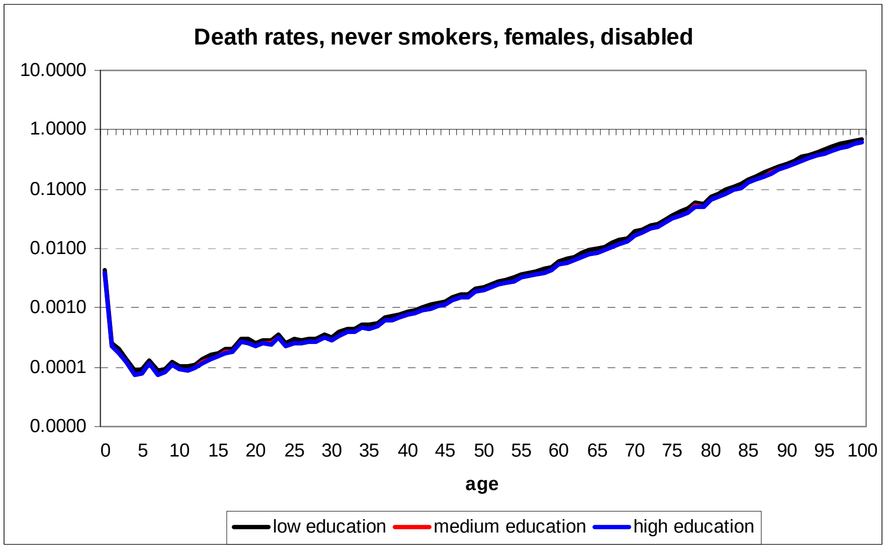
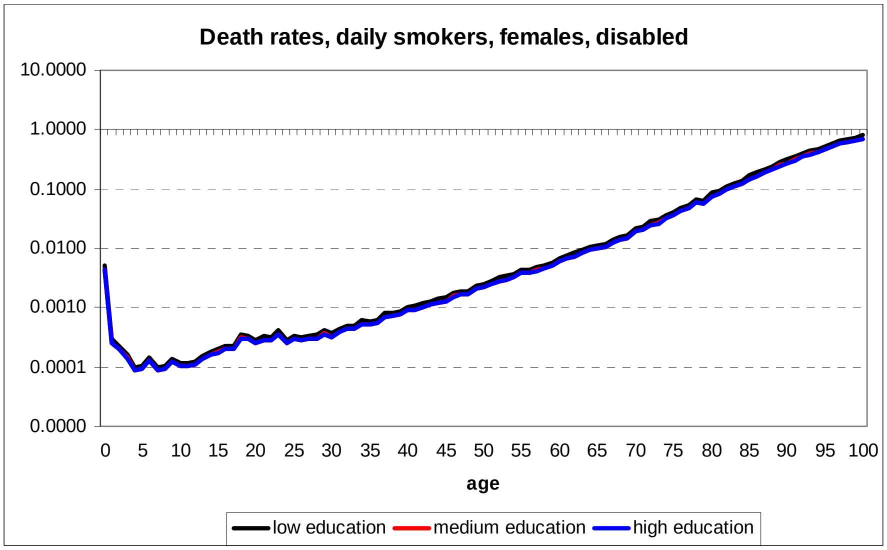


Figure 17 Death rates, females, disabled (1)





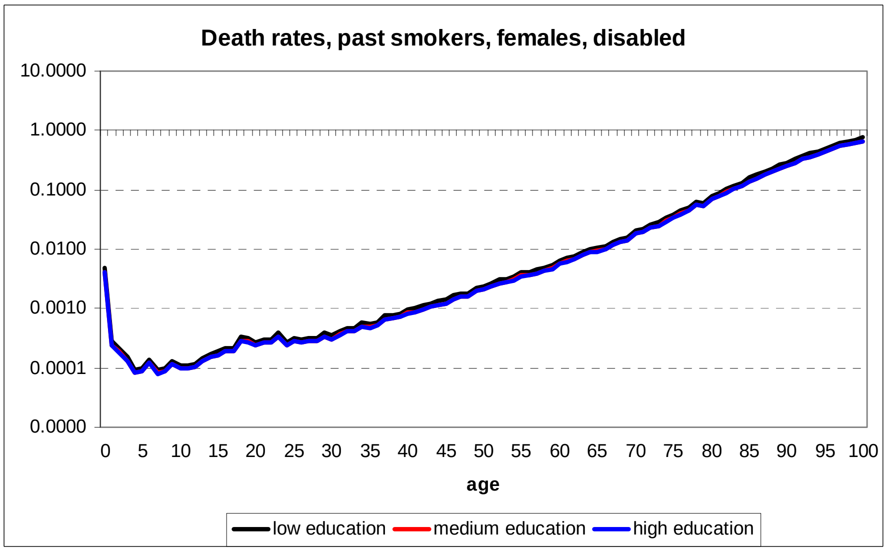
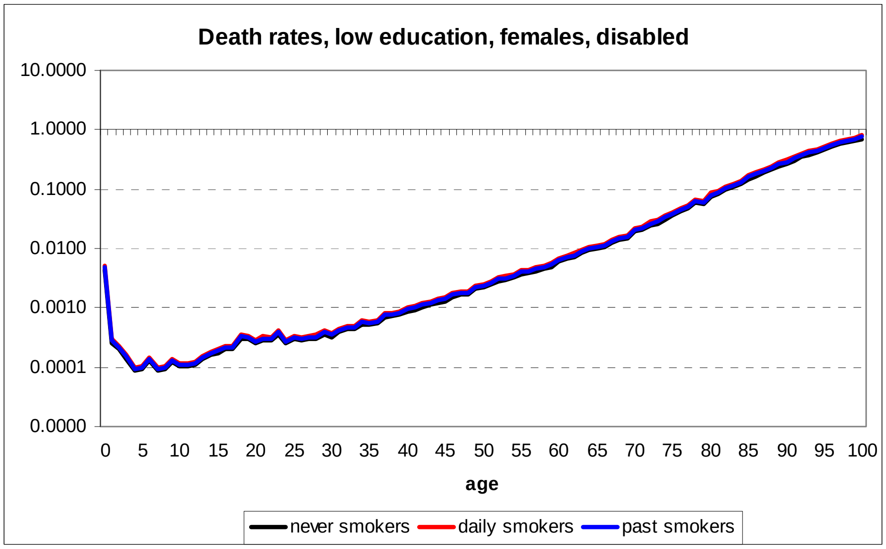
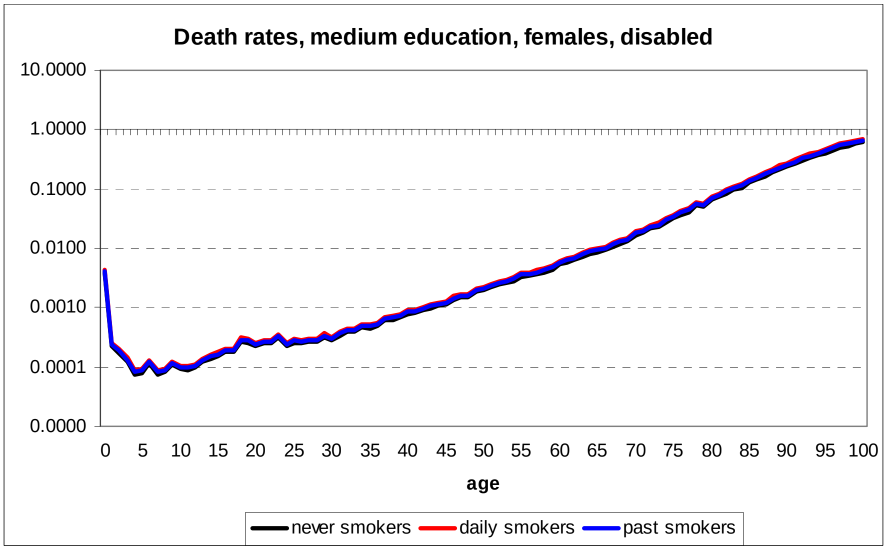


Figure 18 Death rates, females, disabled (2)





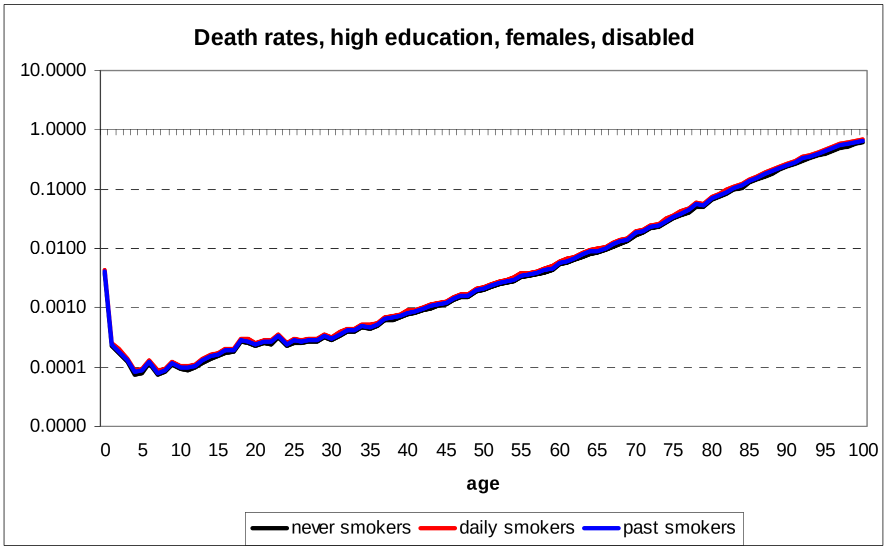
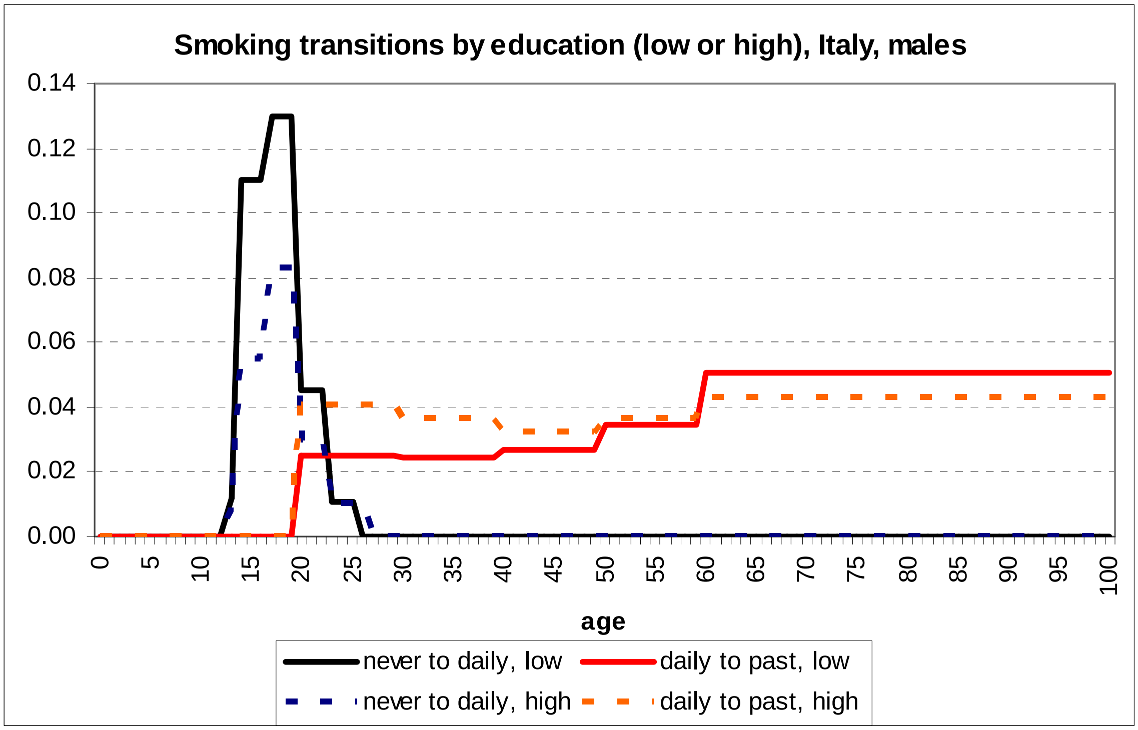


Figure 19 Smoking rates, males and females, baseline scenario



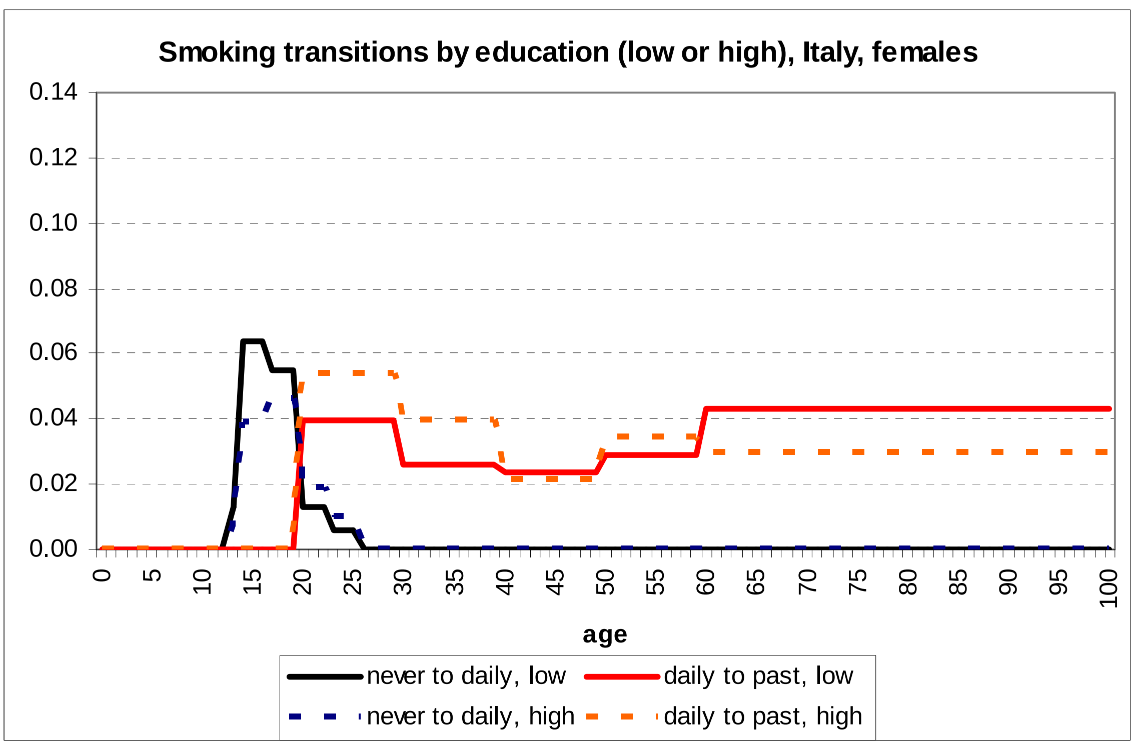
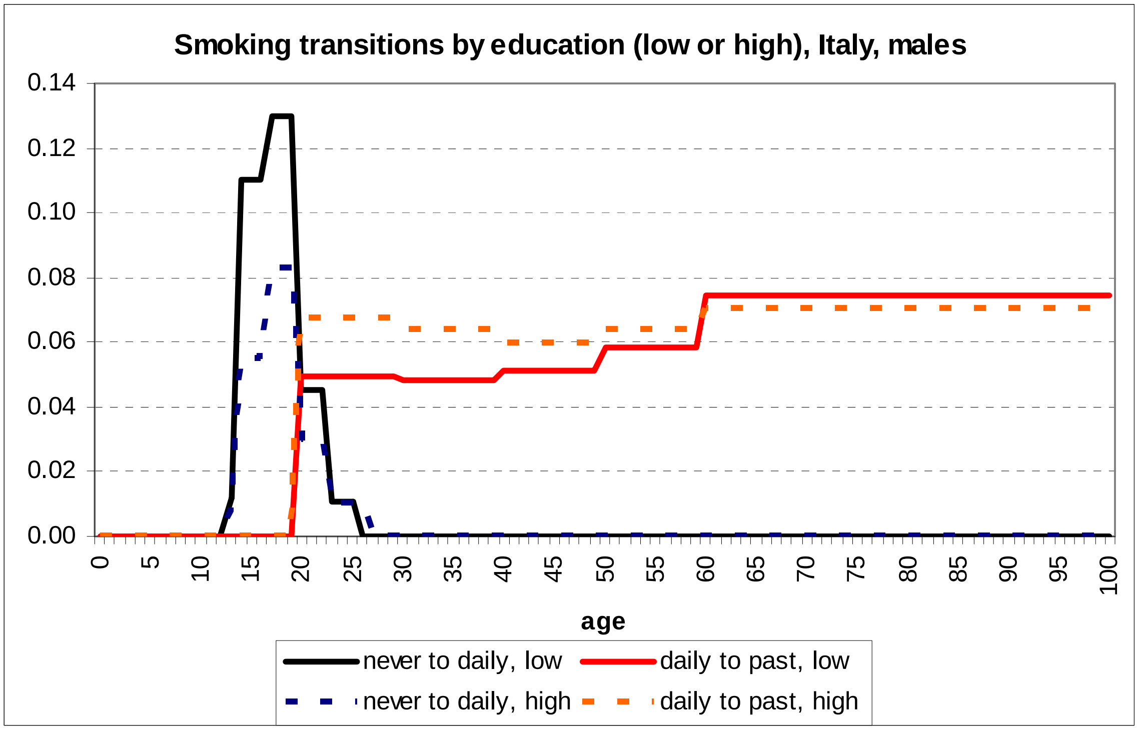


Figure 20 Smoking rates, males and females, intervention scenario



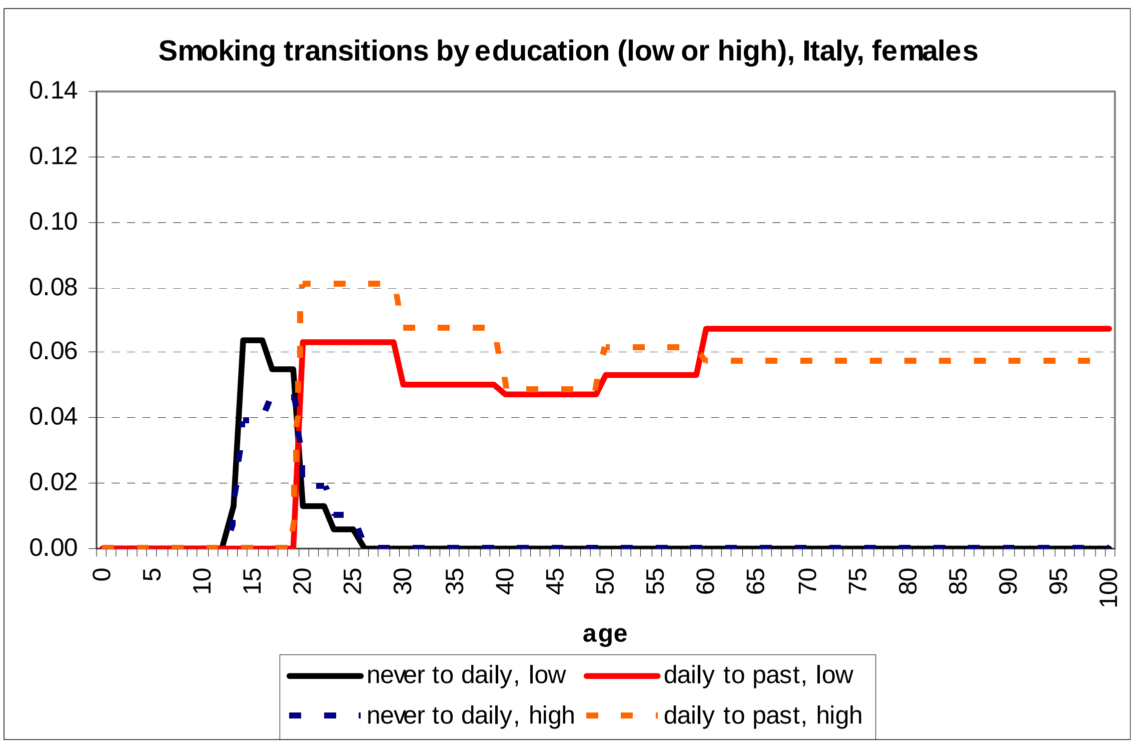


Figure 21 Transitions to higher levels of education

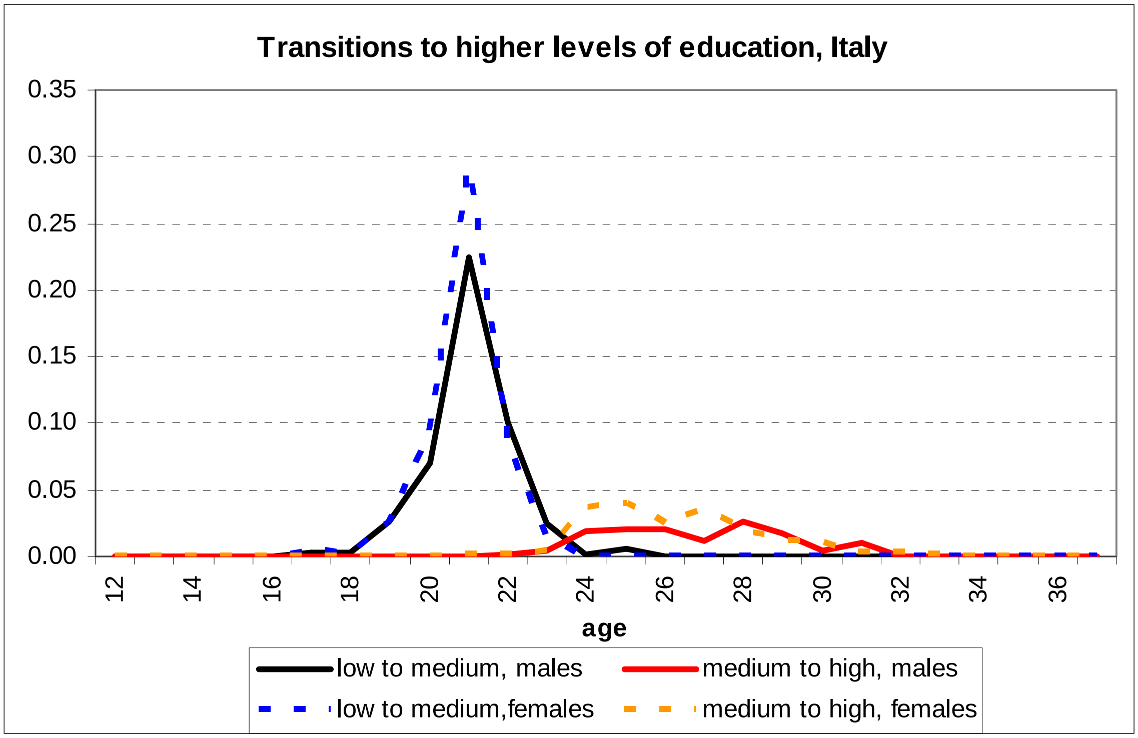


Figure 22 Trends in smoking status, baseline scenario, total cohort

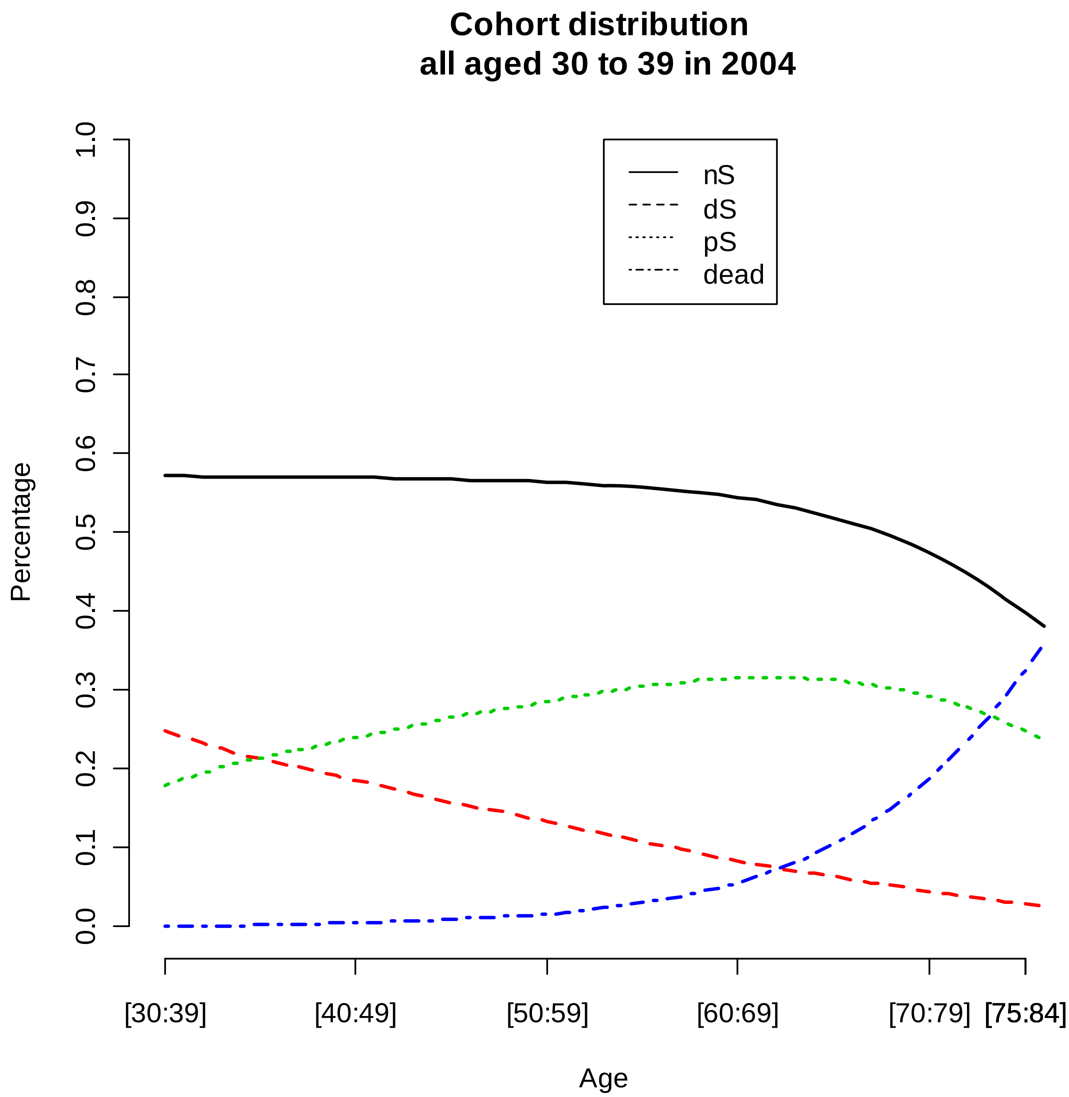


Figure 23 Trends in smoking status, baseline scenario, males

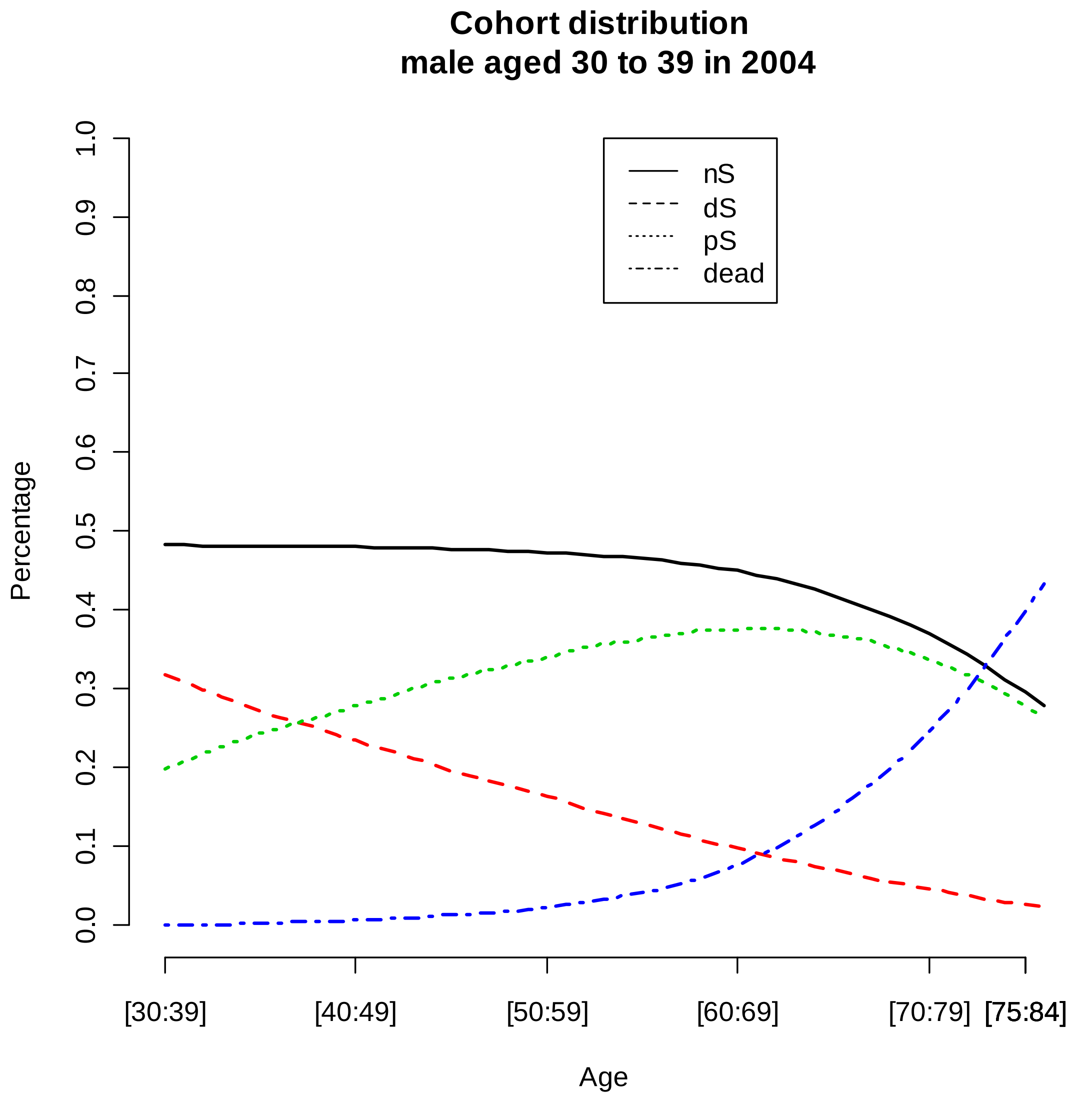


Figure 24 Trends in smoking status, baseline scenario, females

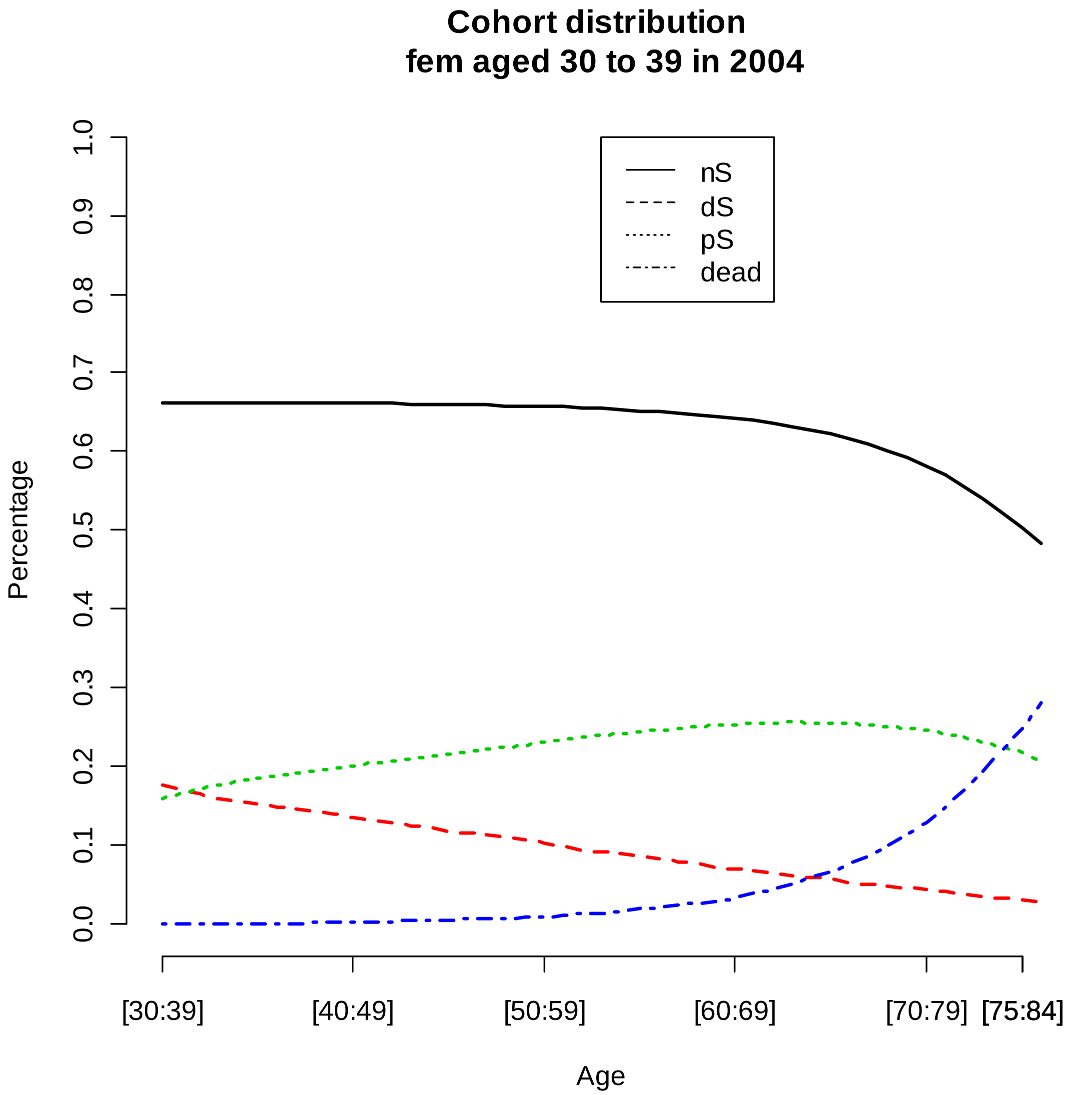


Figure 25 Trends in smoking status, baseline scenario, low educated

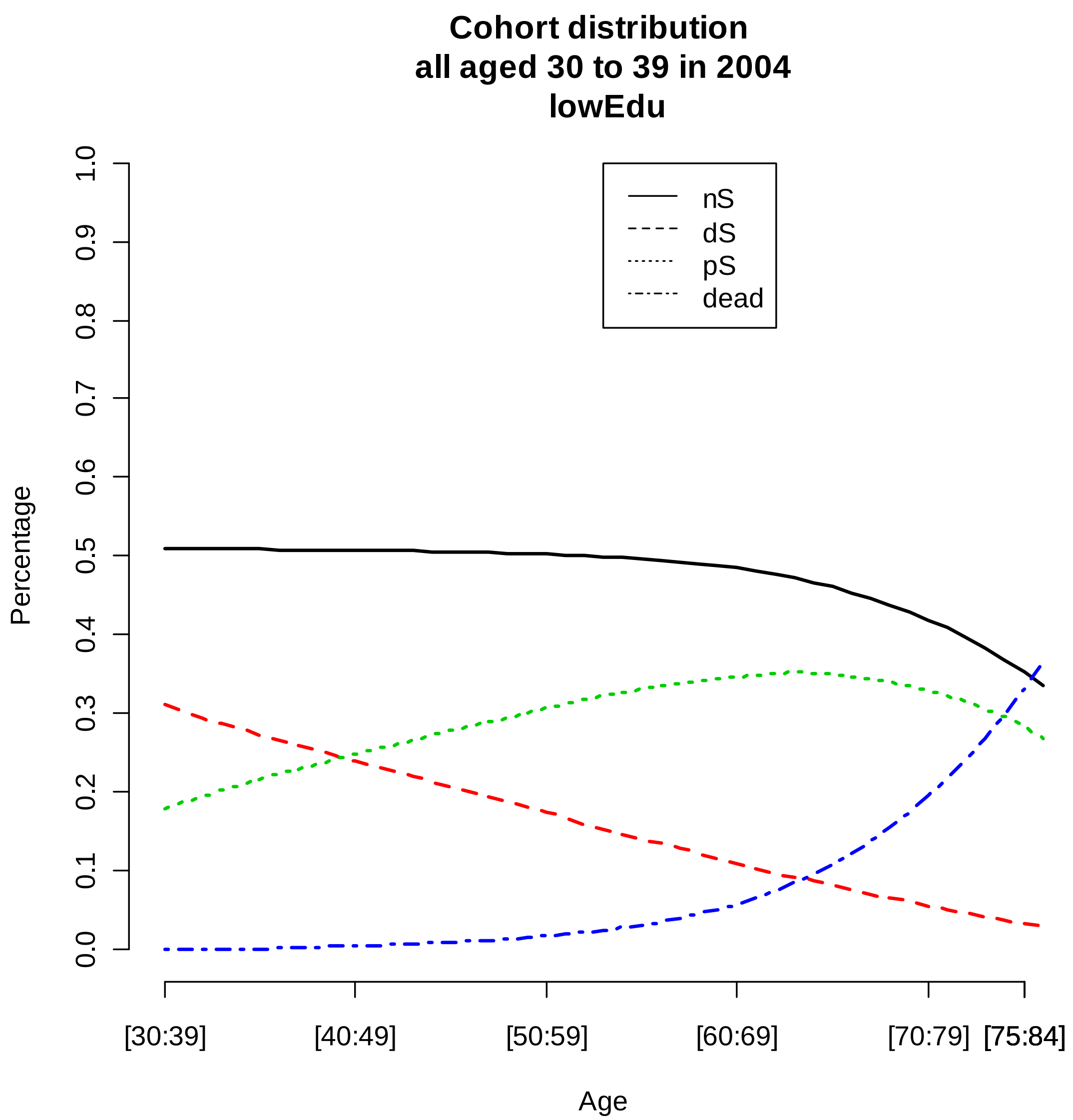


Figure 26 Trends in smoking status, baseline scenario, high educated

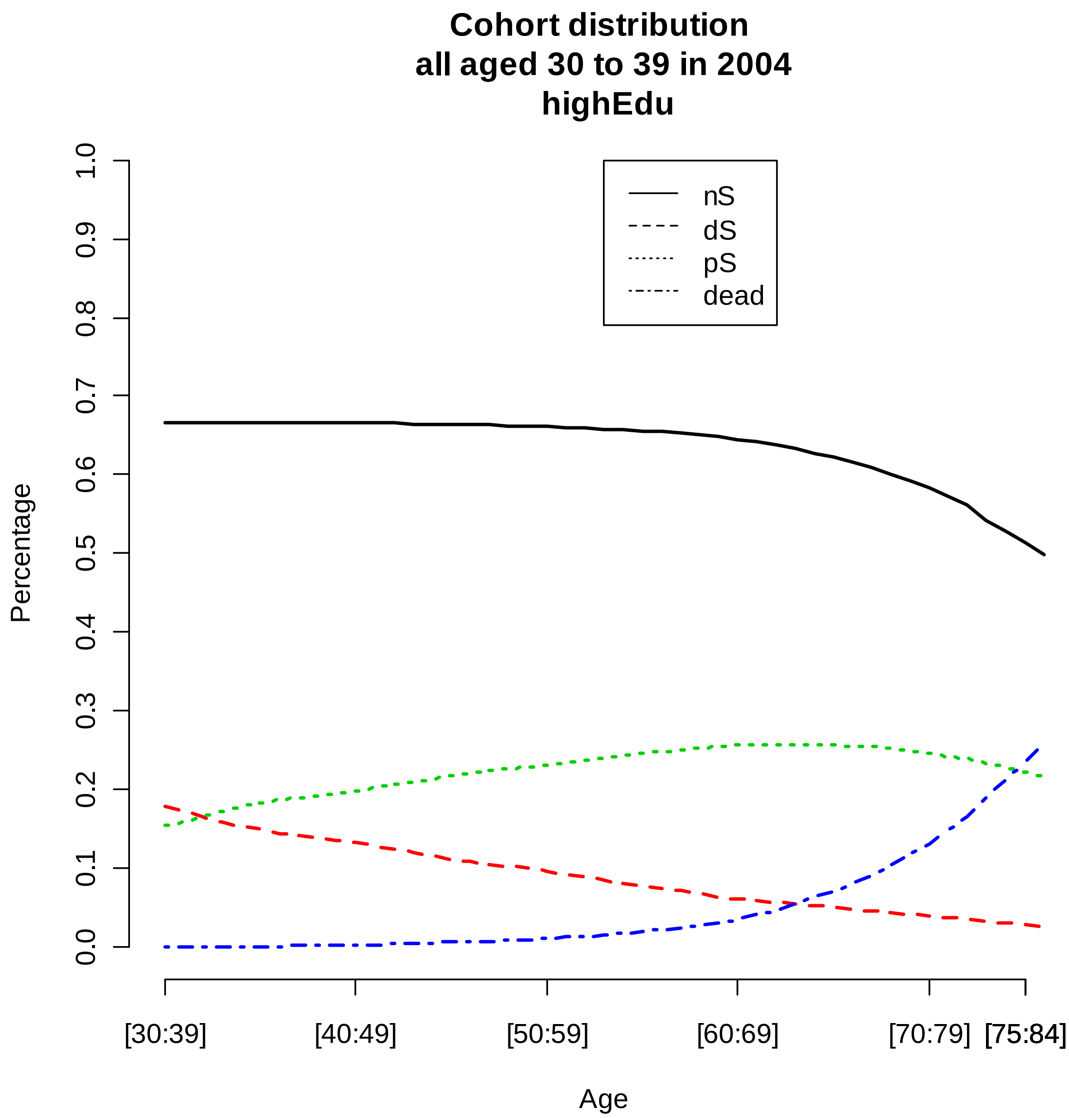


Figure 27 Trends in disability status, baseline scenario, total cohort

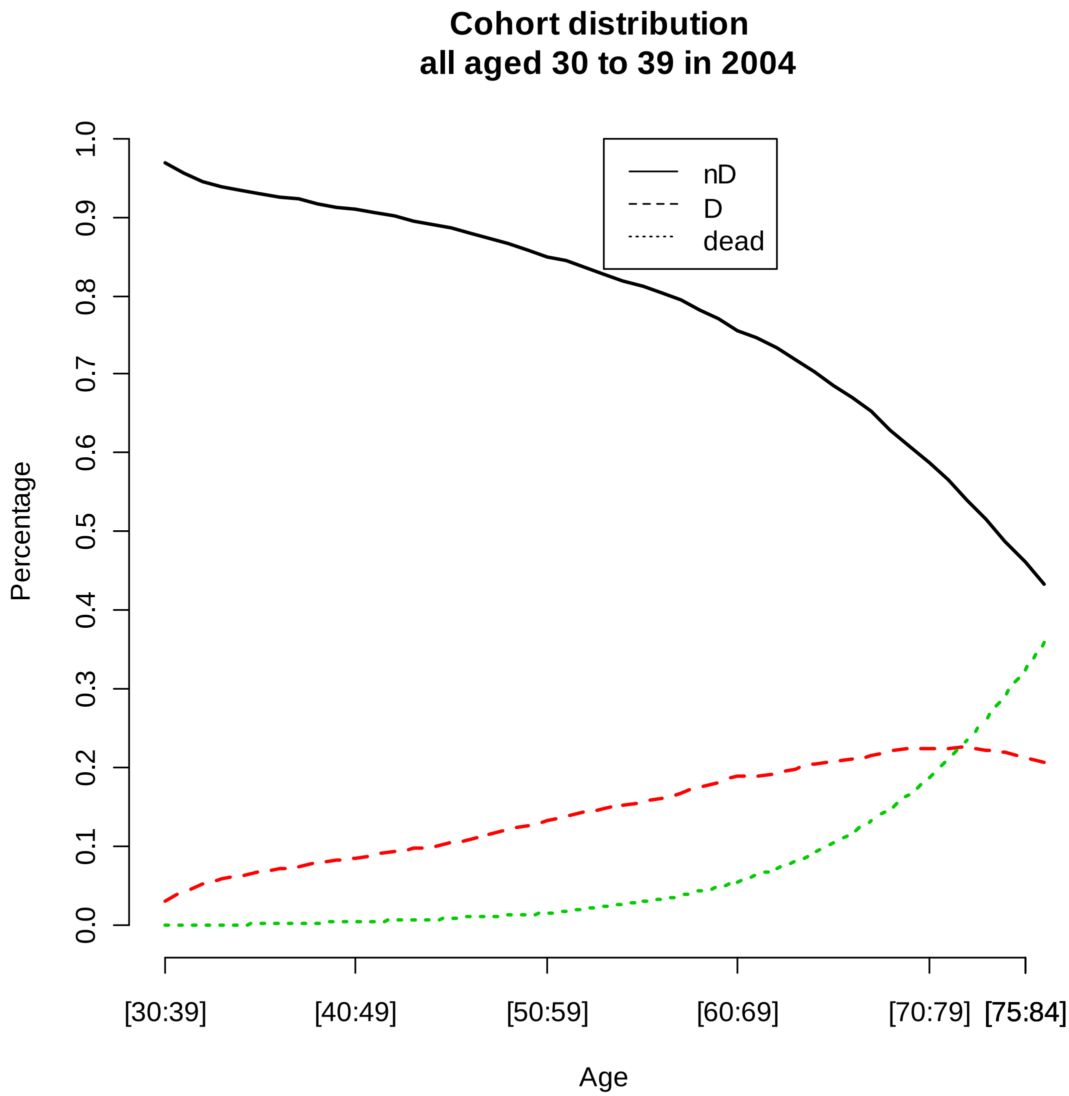


Figure 28 Trends in disability status, baseline scenario, males

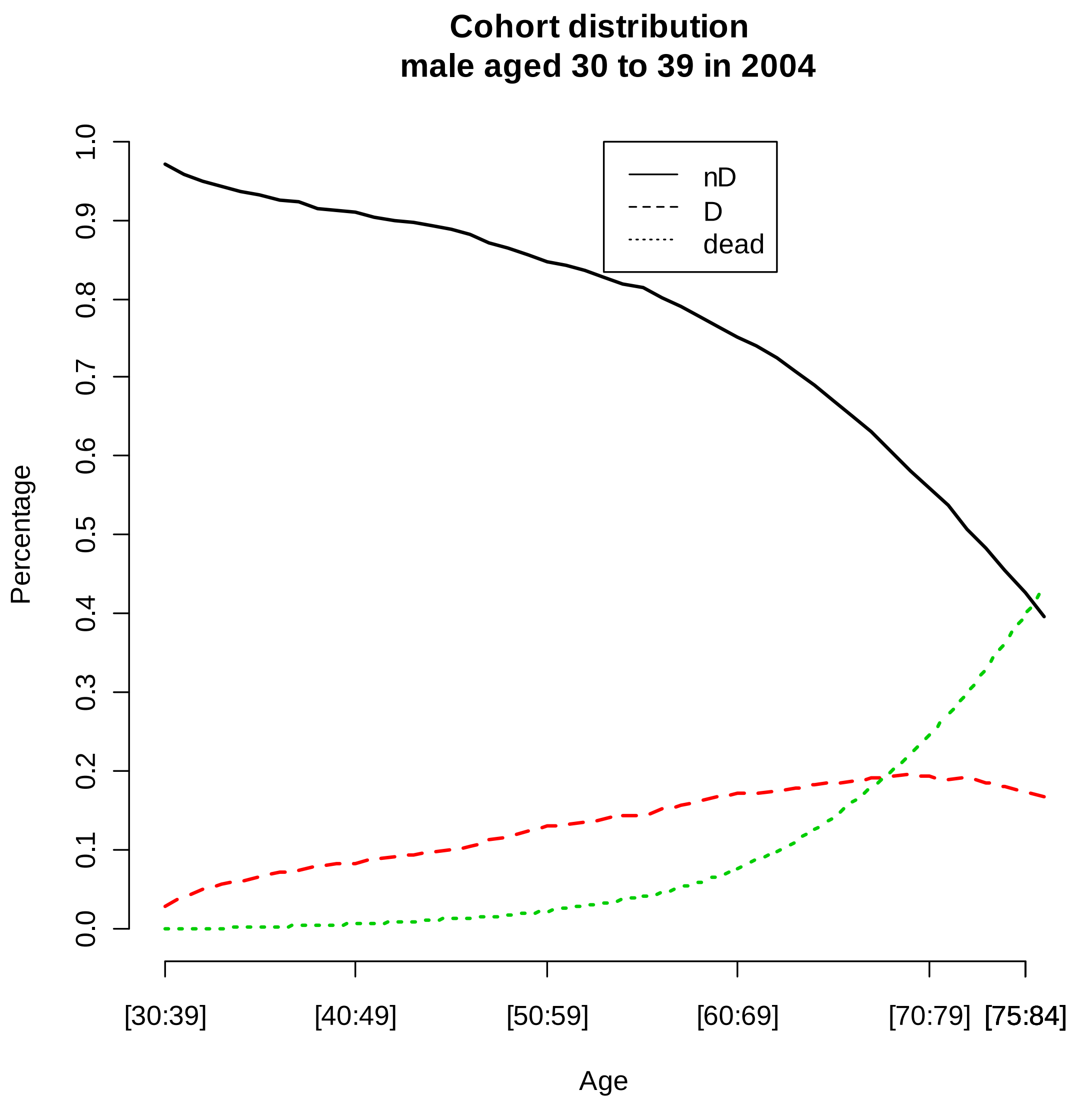


Figure 29 Trends in disability status, baseline scenario, females

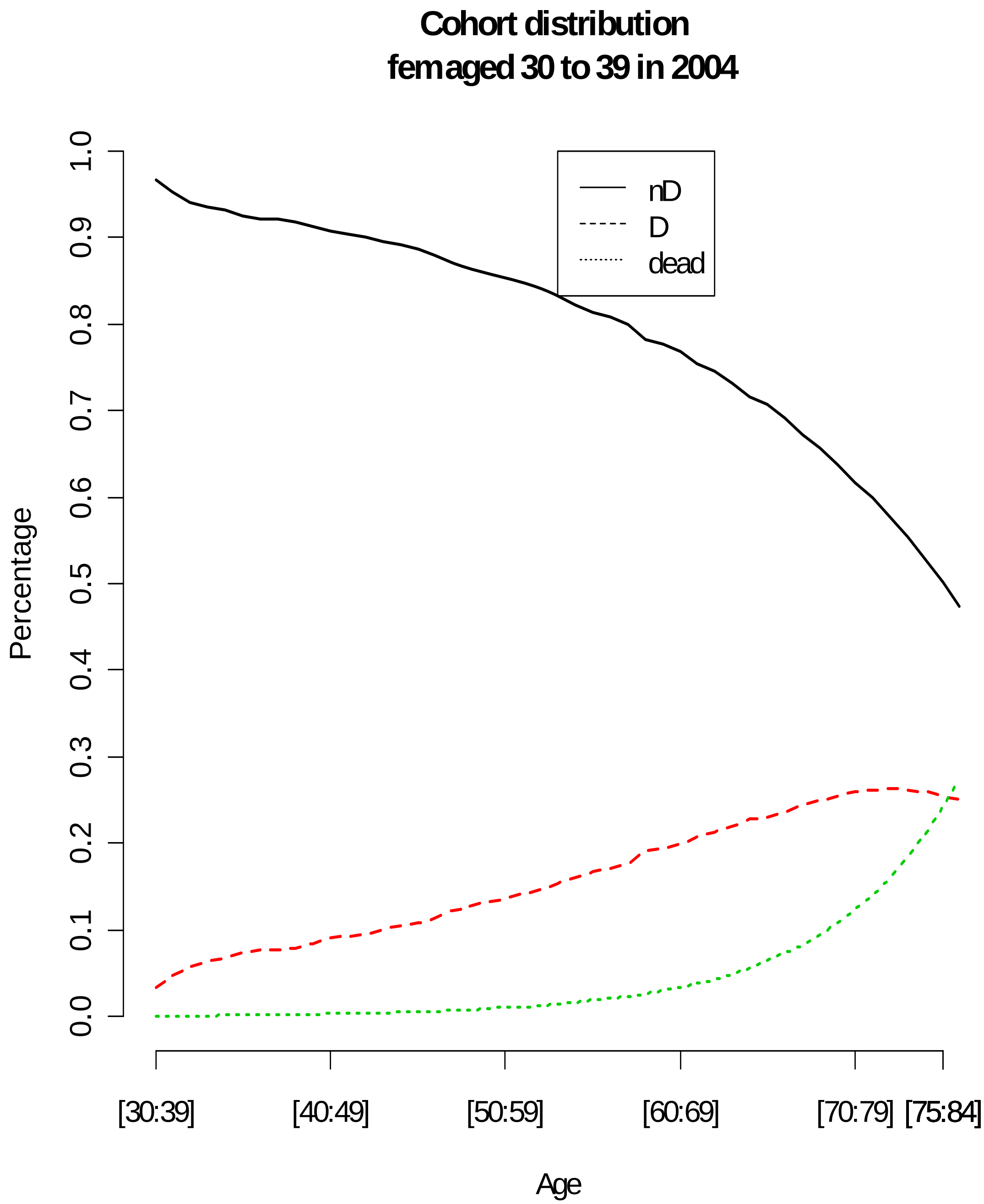


Figure 30 Trends in disability status, baseline scenario, low educated

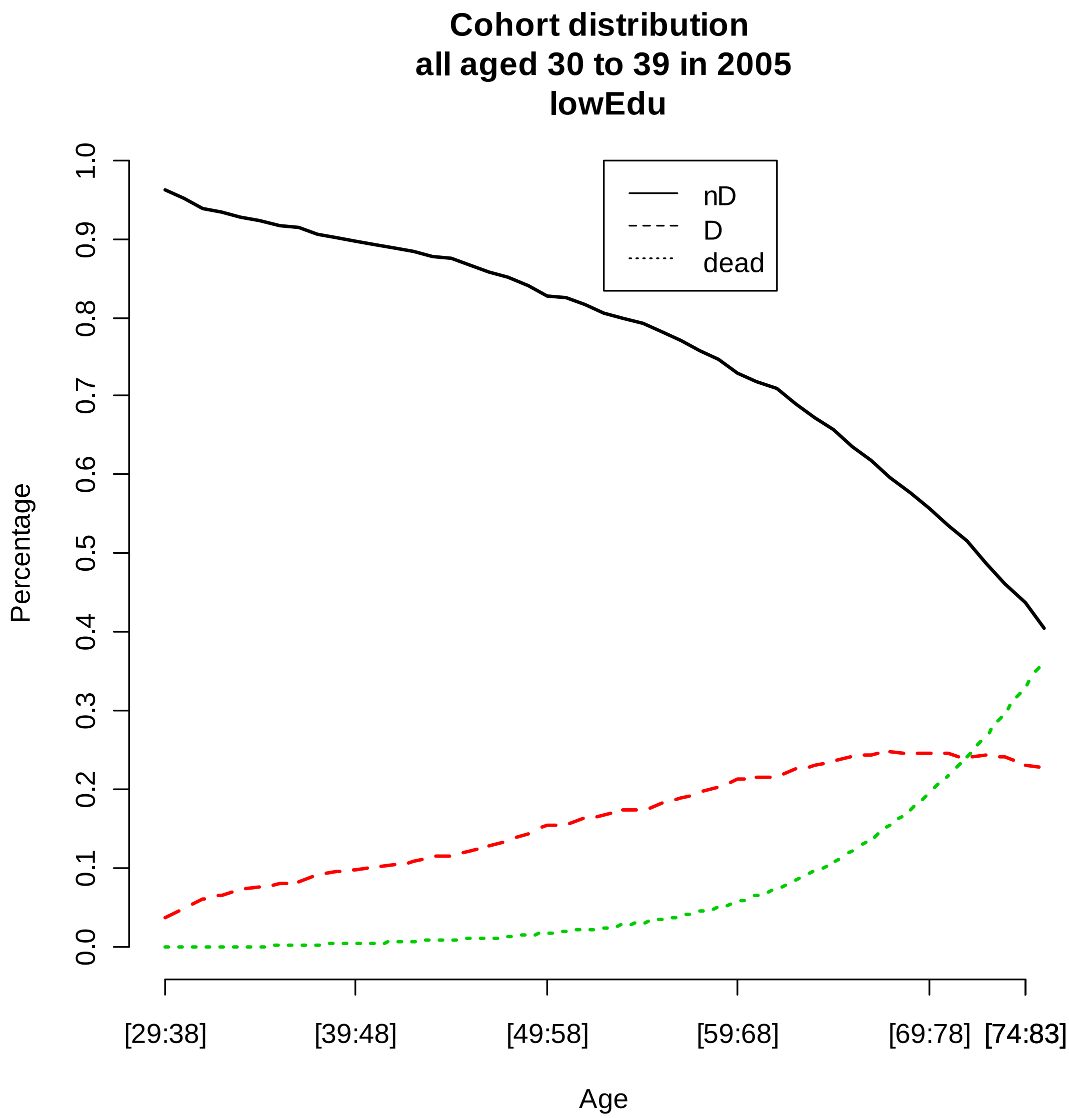


Figure 31 Trends in disability status, baseline scenario, high educated

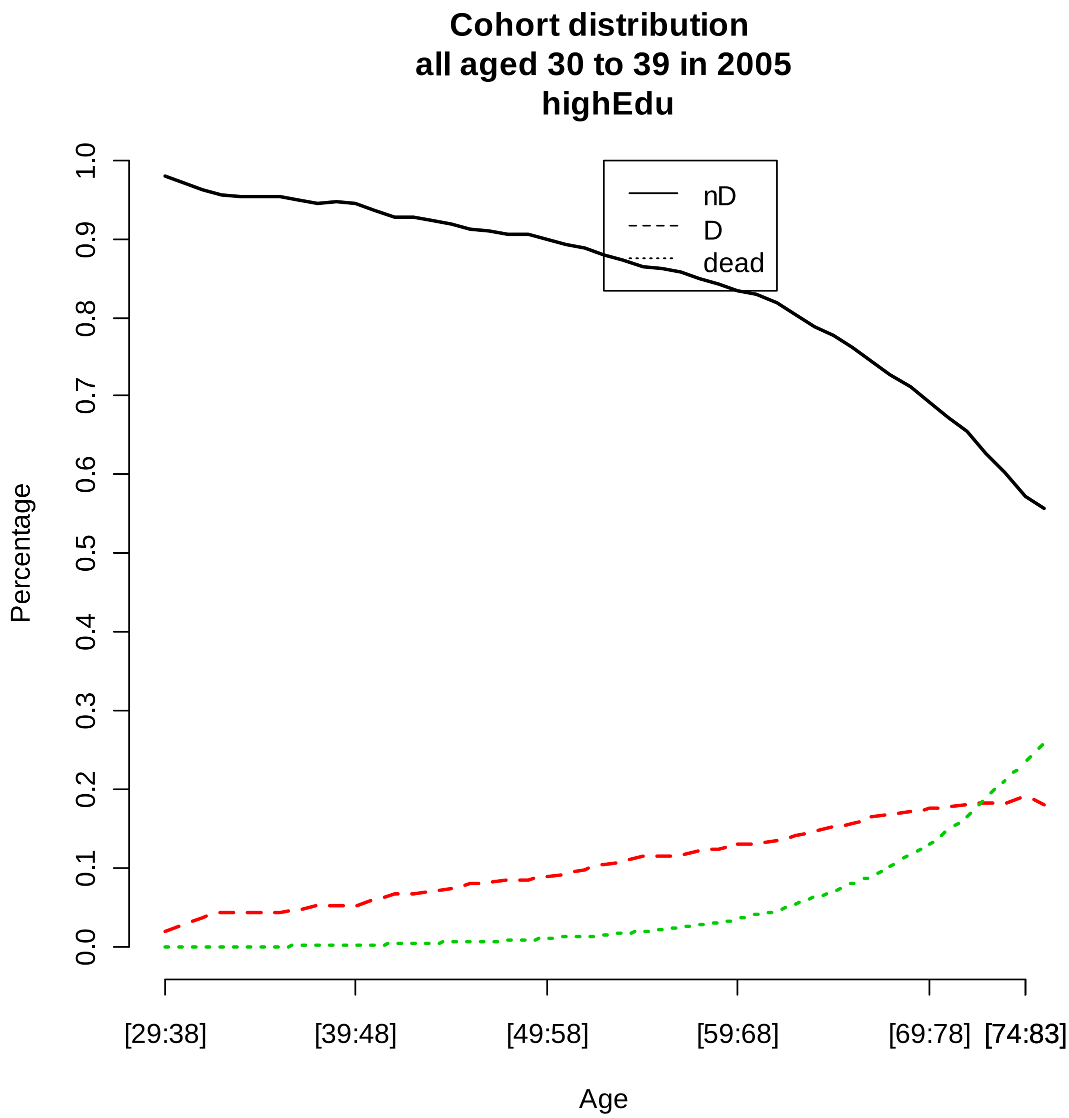


Figure 32 Trends in disability status, baseline scenario, total cohort age 40-49

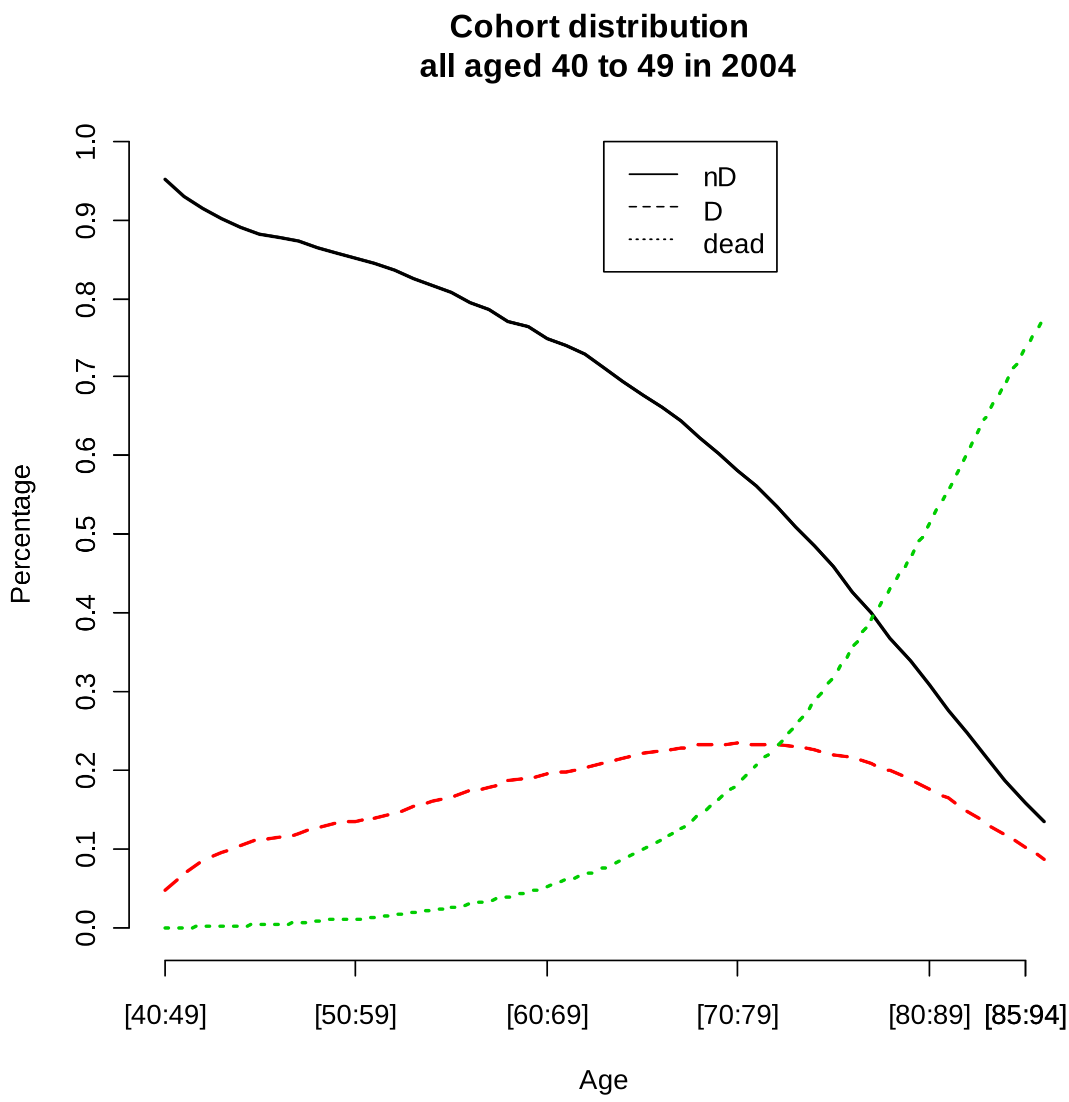


Figure 33 Trends in disability status, baseline scenario, total cohort age 50-59

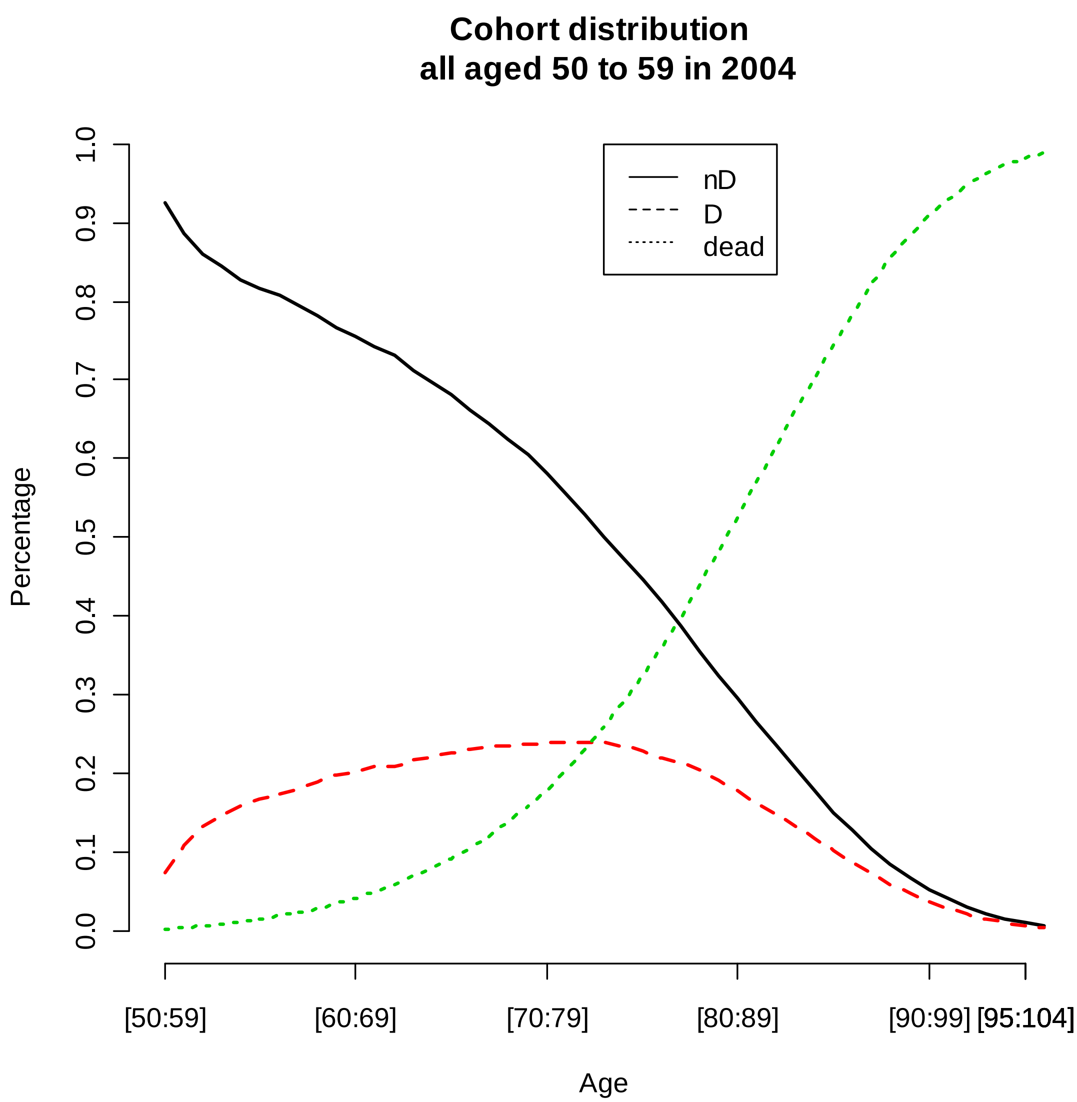


Figure 34 Trends in smoking status, intervention scenario, total cohort

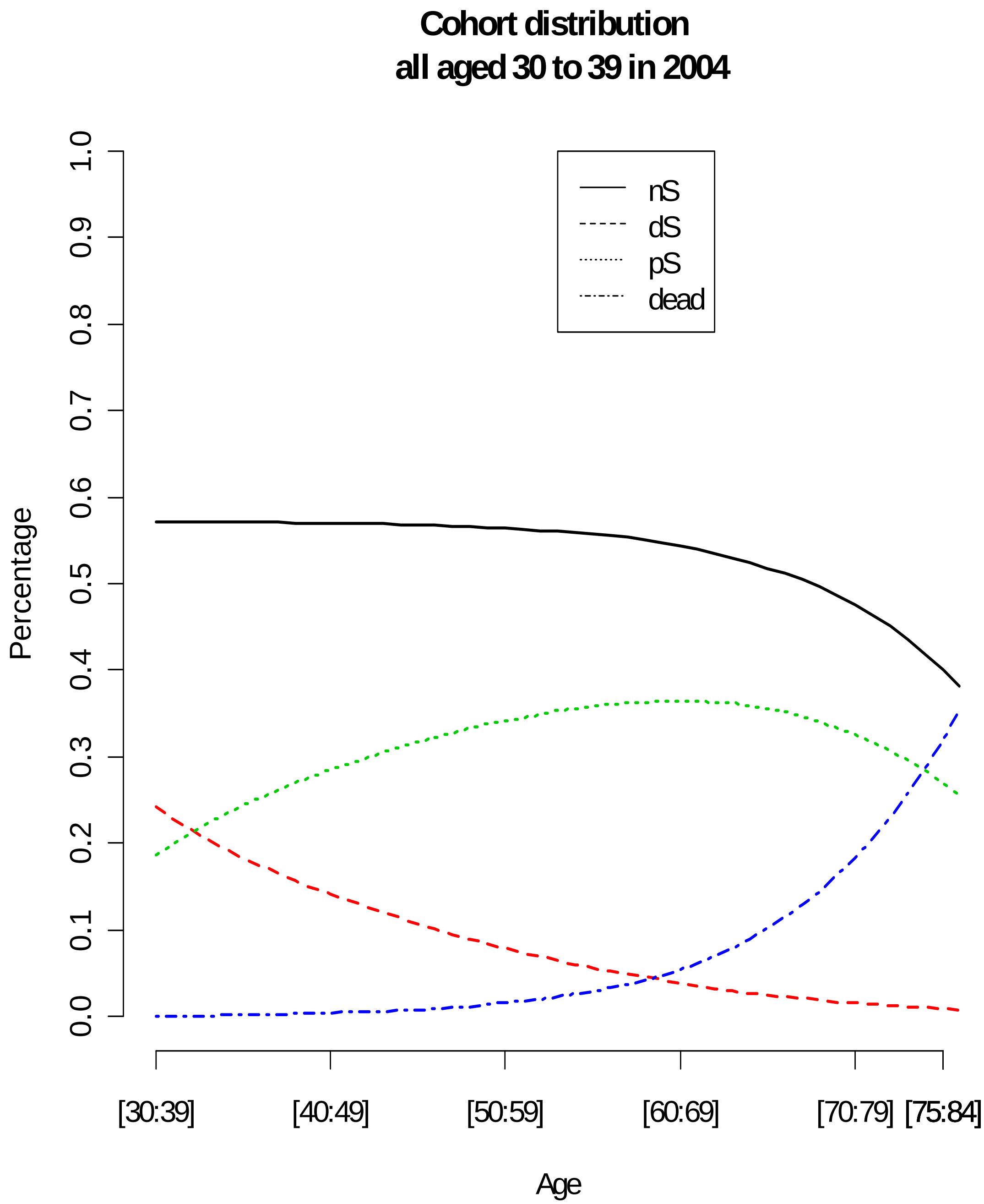


Figure 35 Trends in smoking status, intervention scenario, males

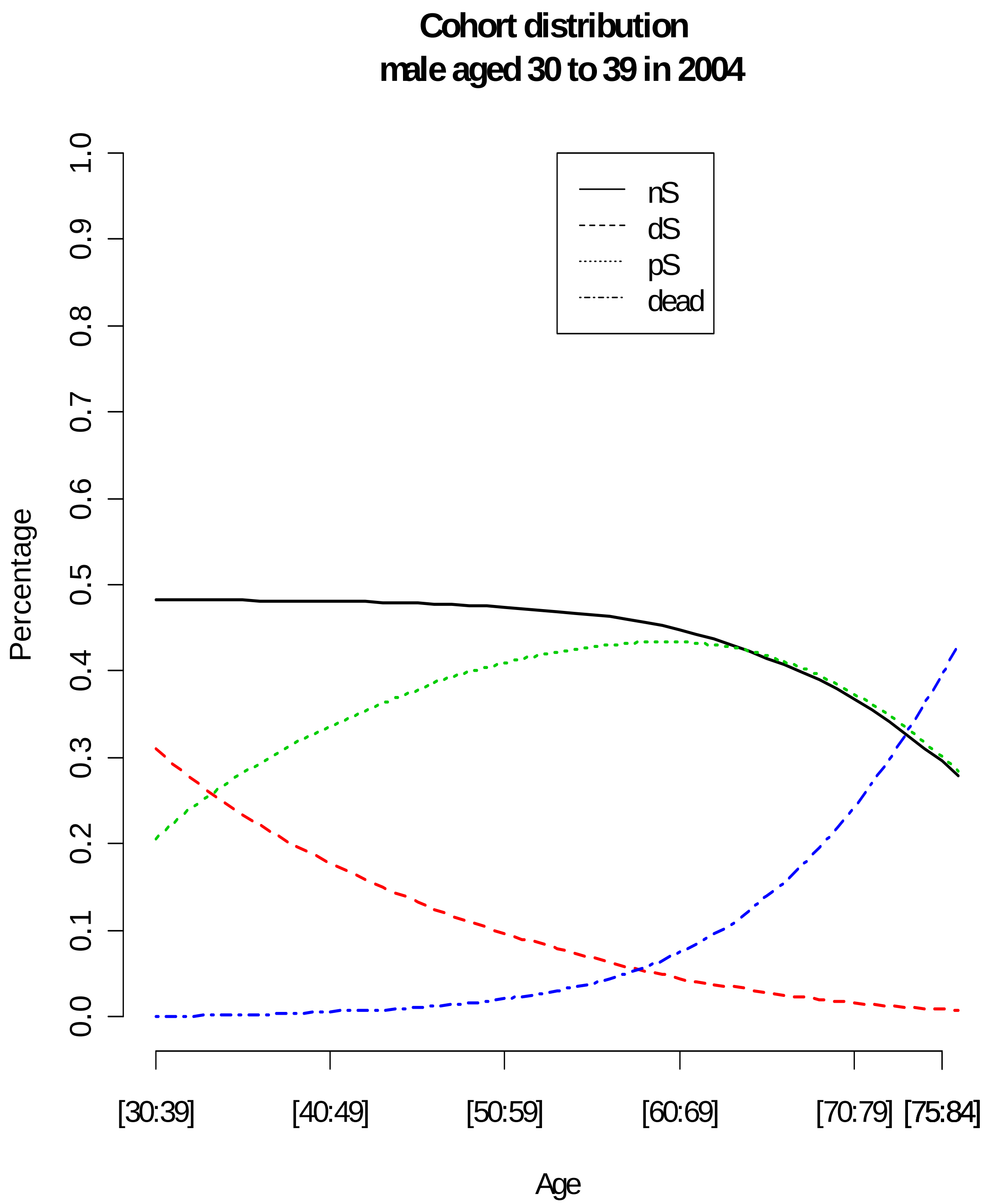


Figure 36 Trends in smoking status, intervention scenario, females

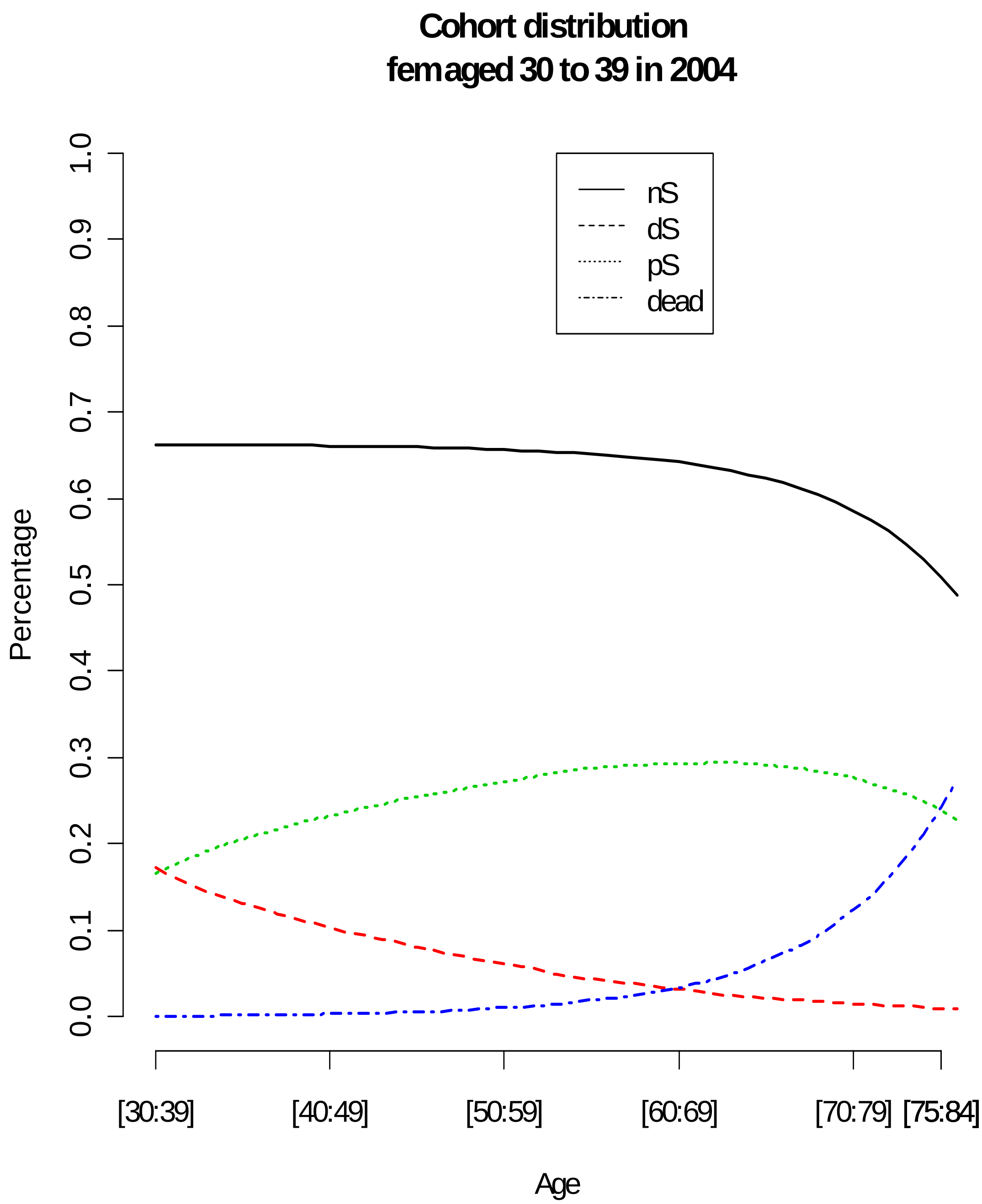


Figure 37 Trends in smoking status, intervention scenario, low education

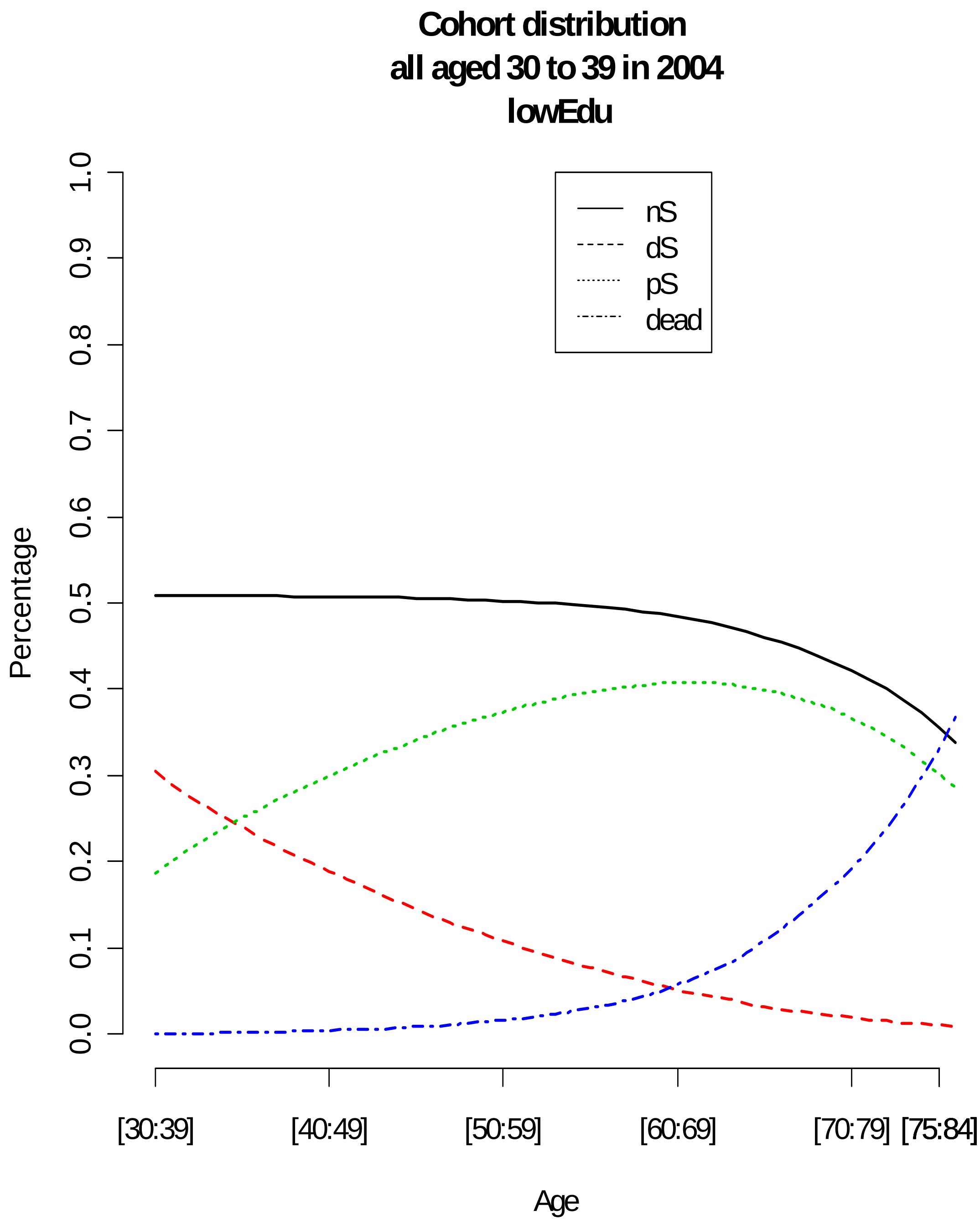


Figure 38 Trends in smoking status, intervention scenario, high education

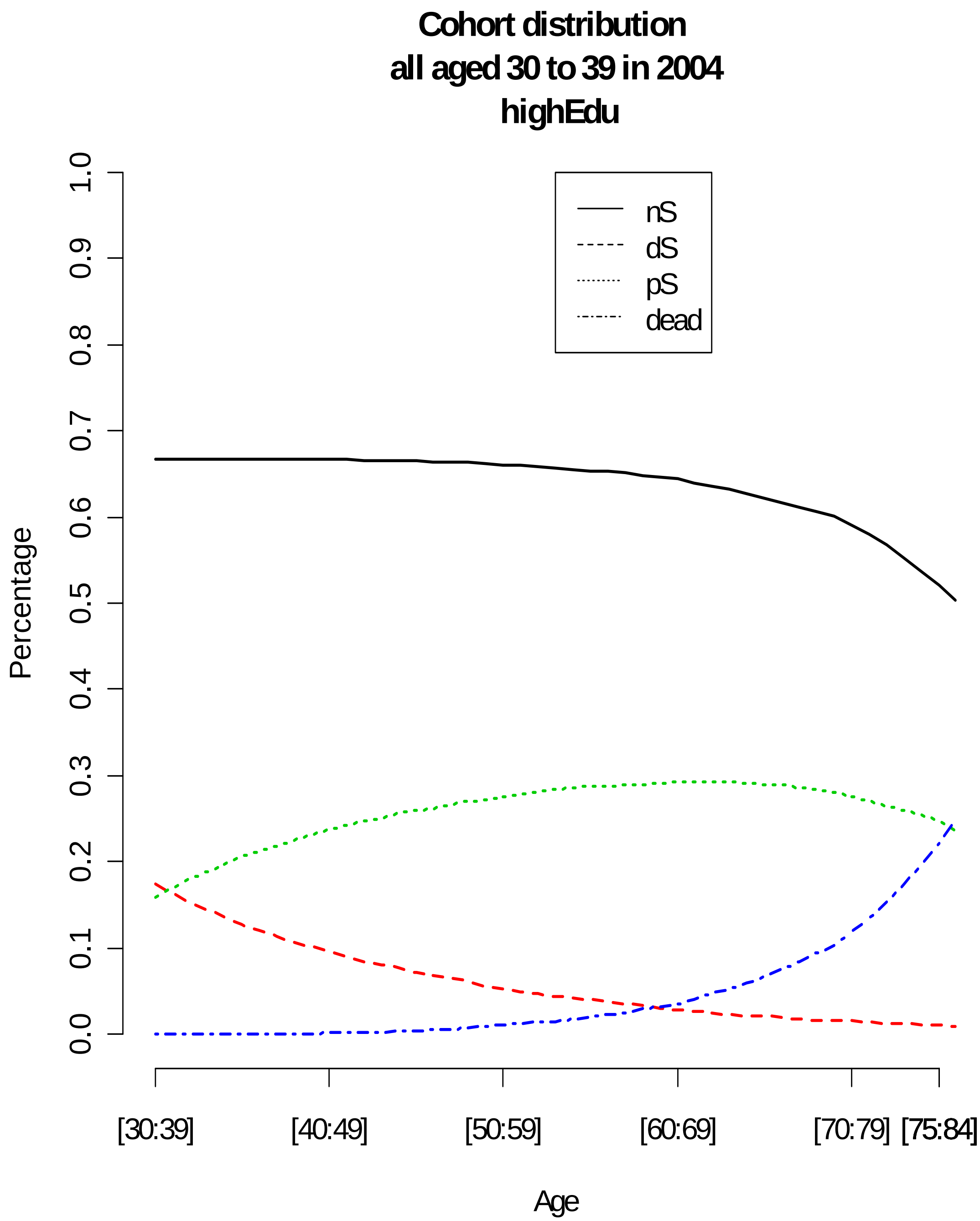


Figure 39 Trends in disability status, intervention scenario,total cohort

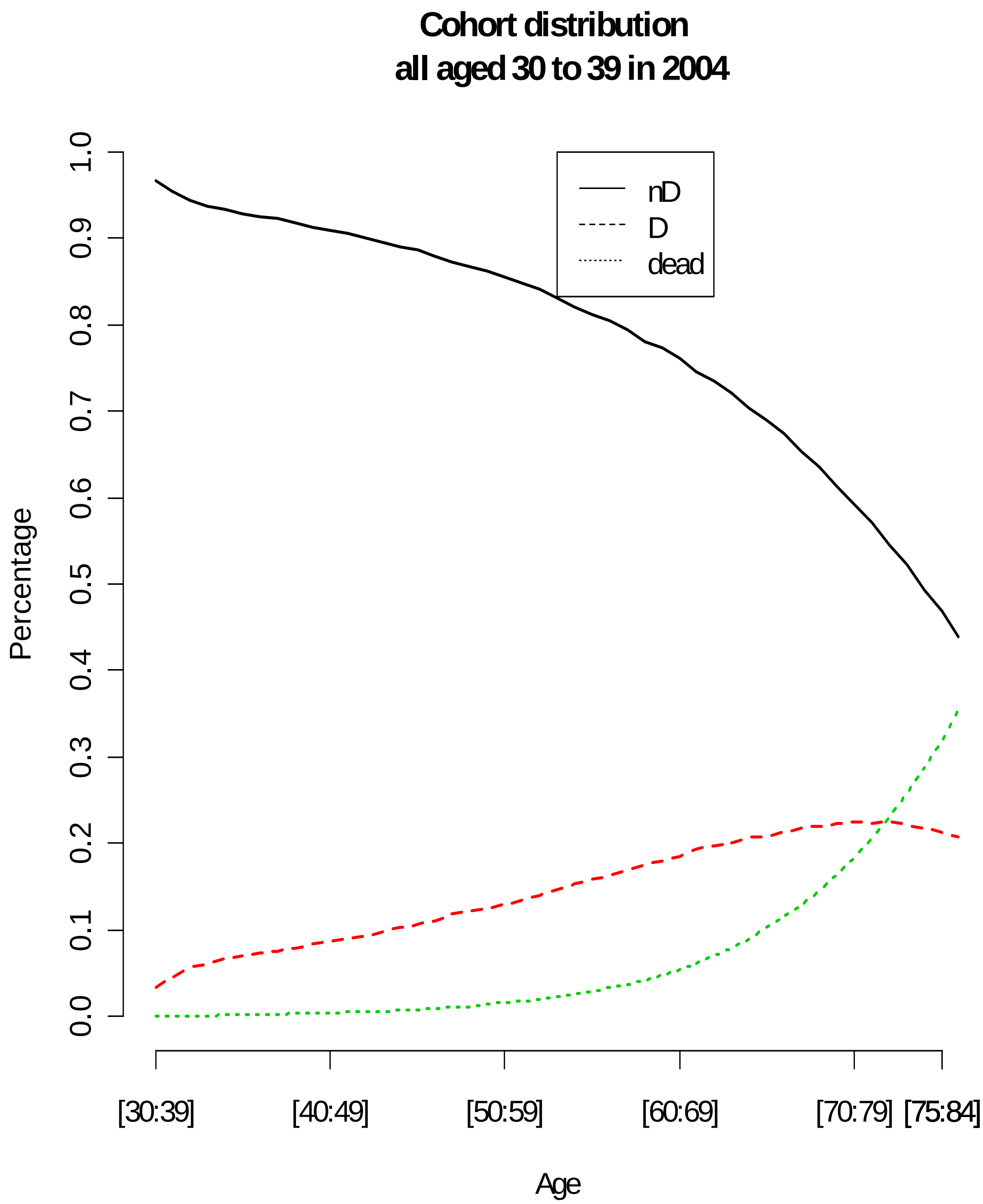


Figure 40 Trends in disability status, intervention scenario, males

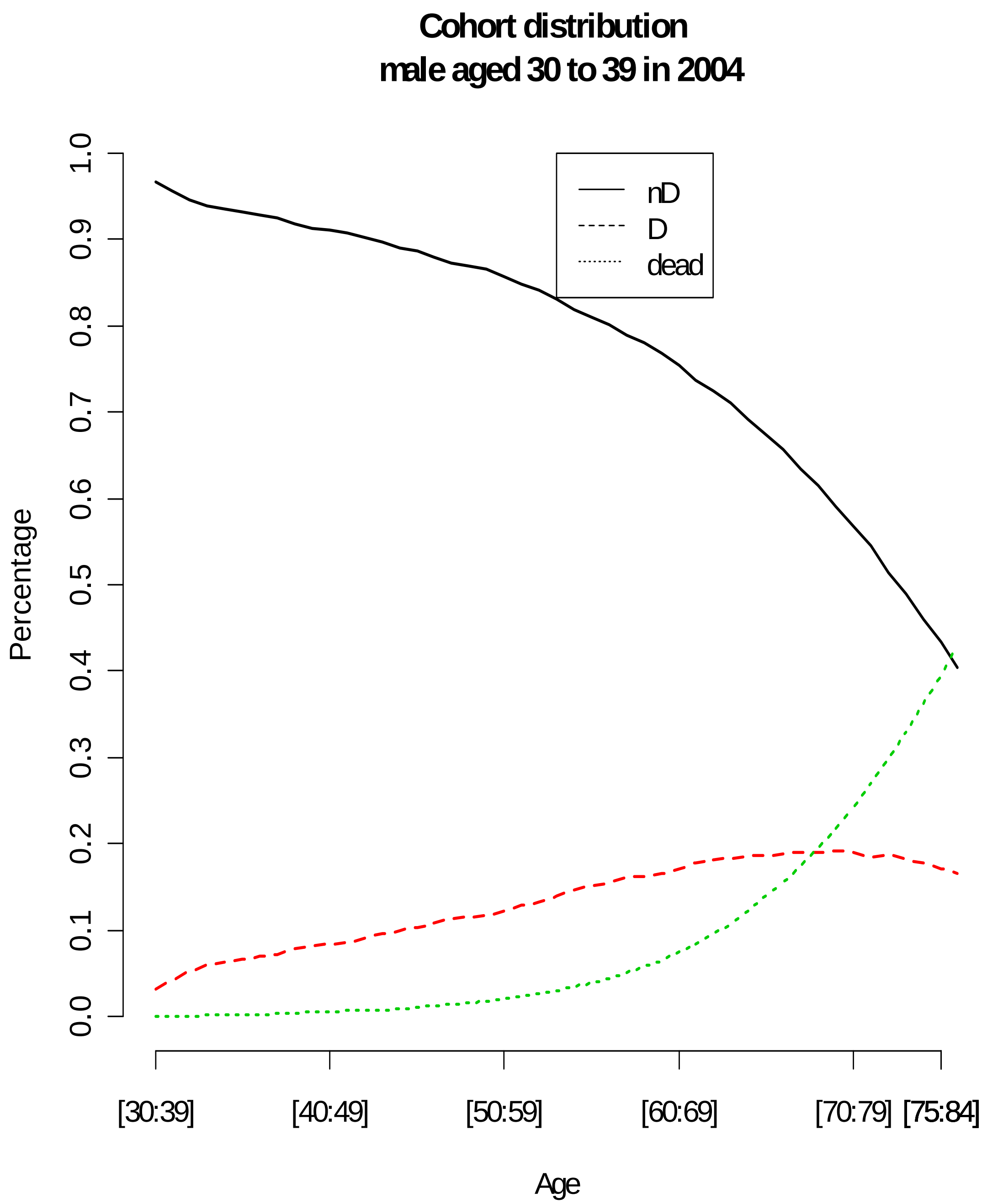


Figure 41 Trends in disability status, intervention scenario, females

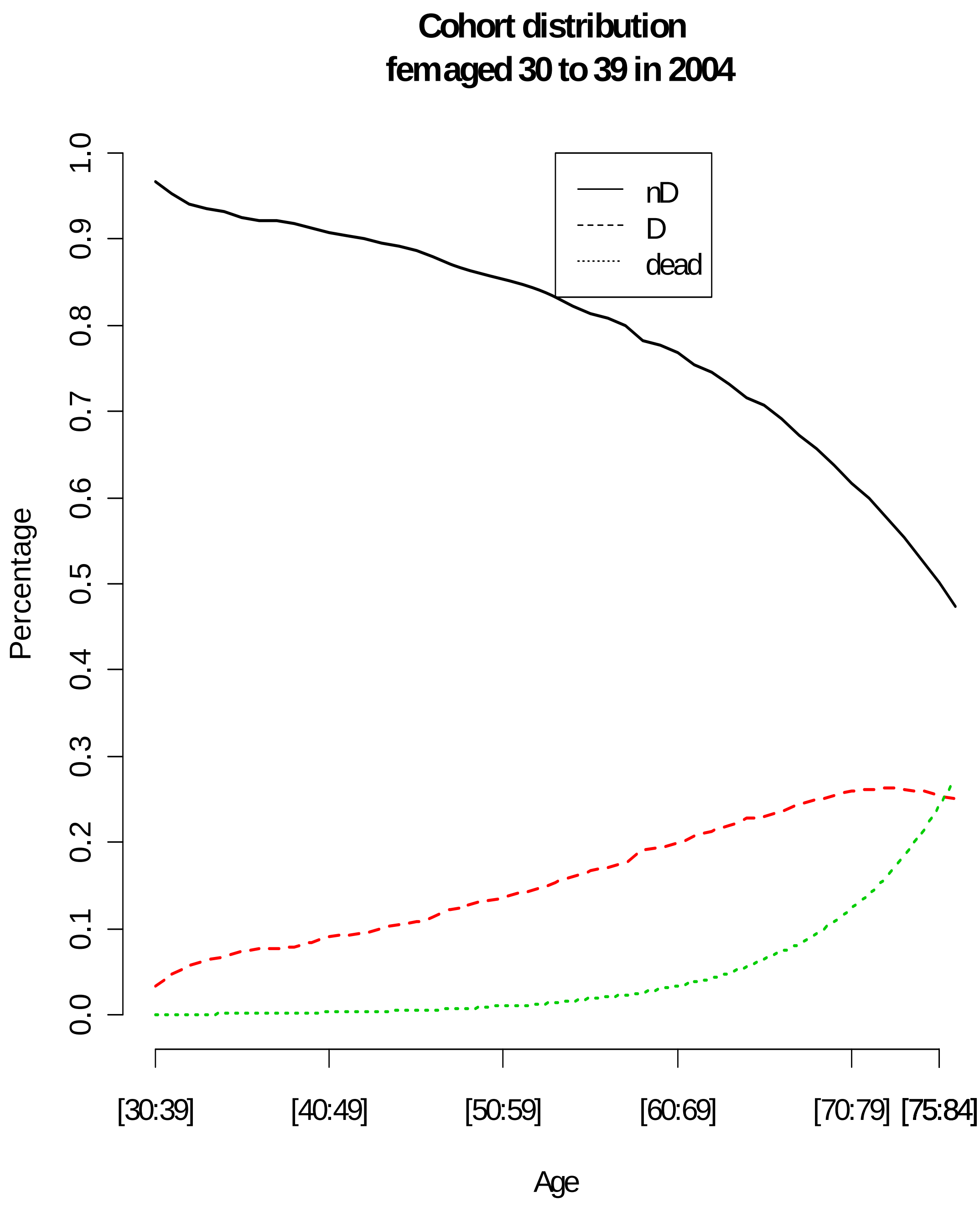


Figure 42 Trends in disability status, intervention scenario, low education

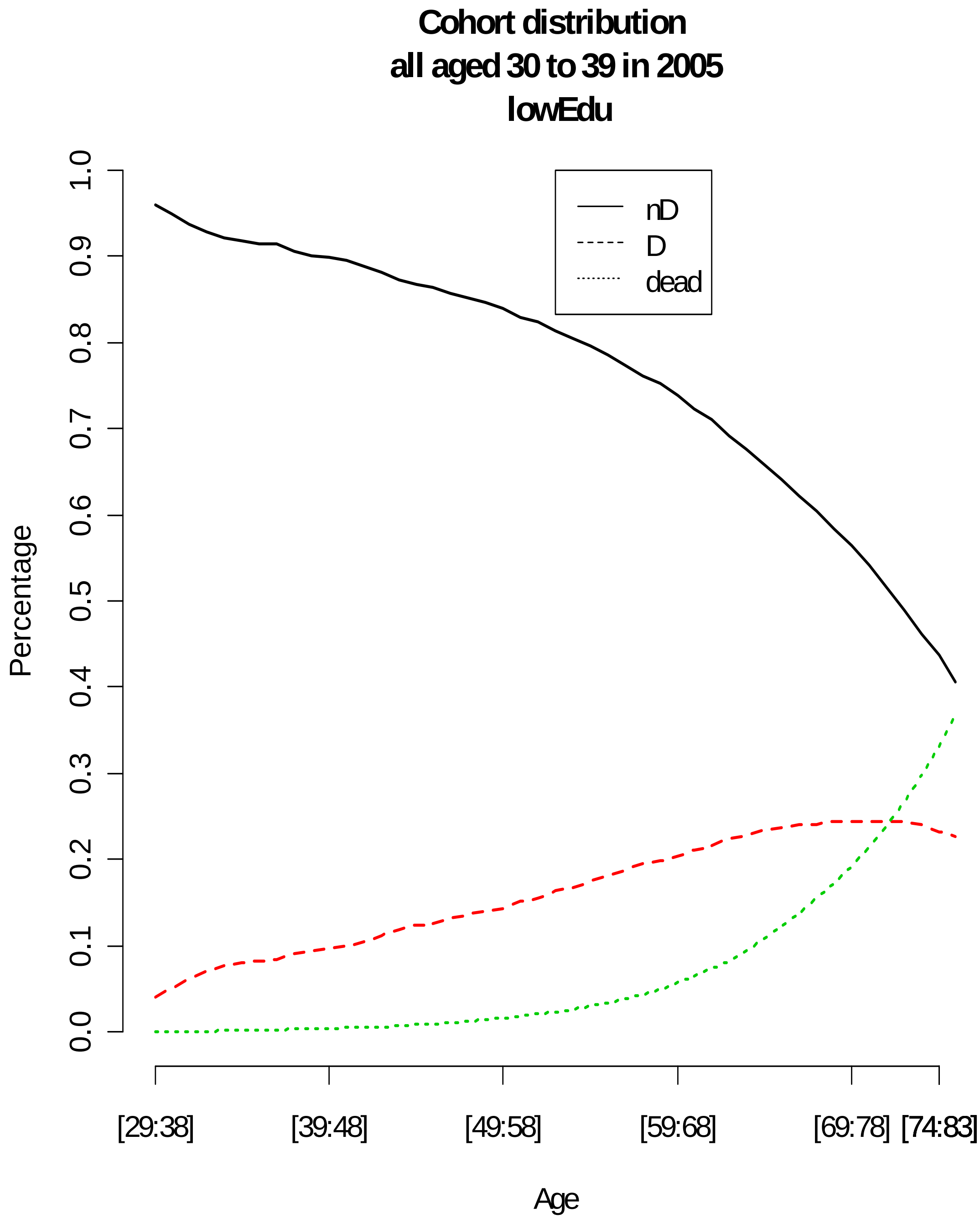


Figure 43 Trends in disability status, intervention scenario, high education

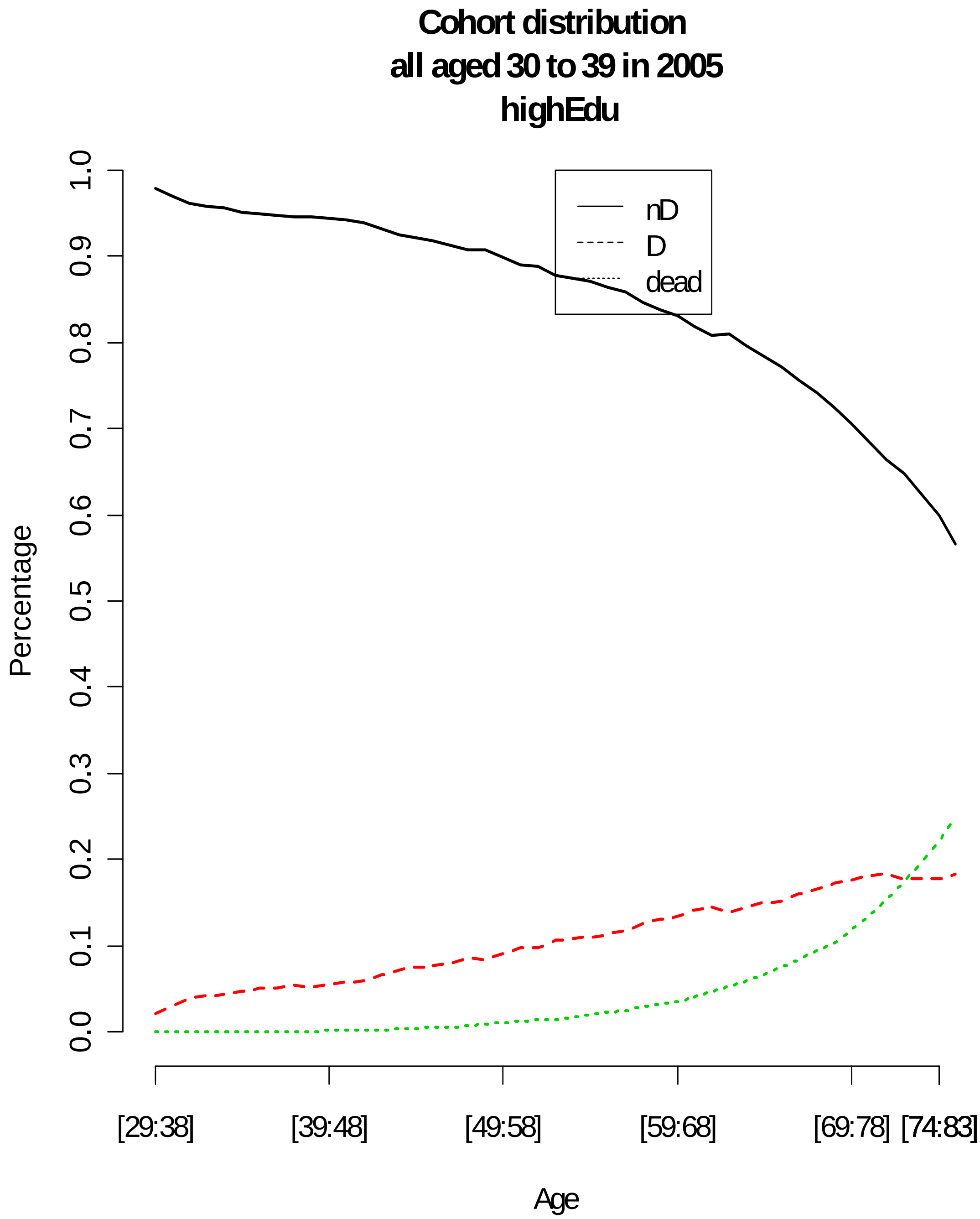


Figure 44 Trends in disability status, intervention scenario, total cohort age 40-49

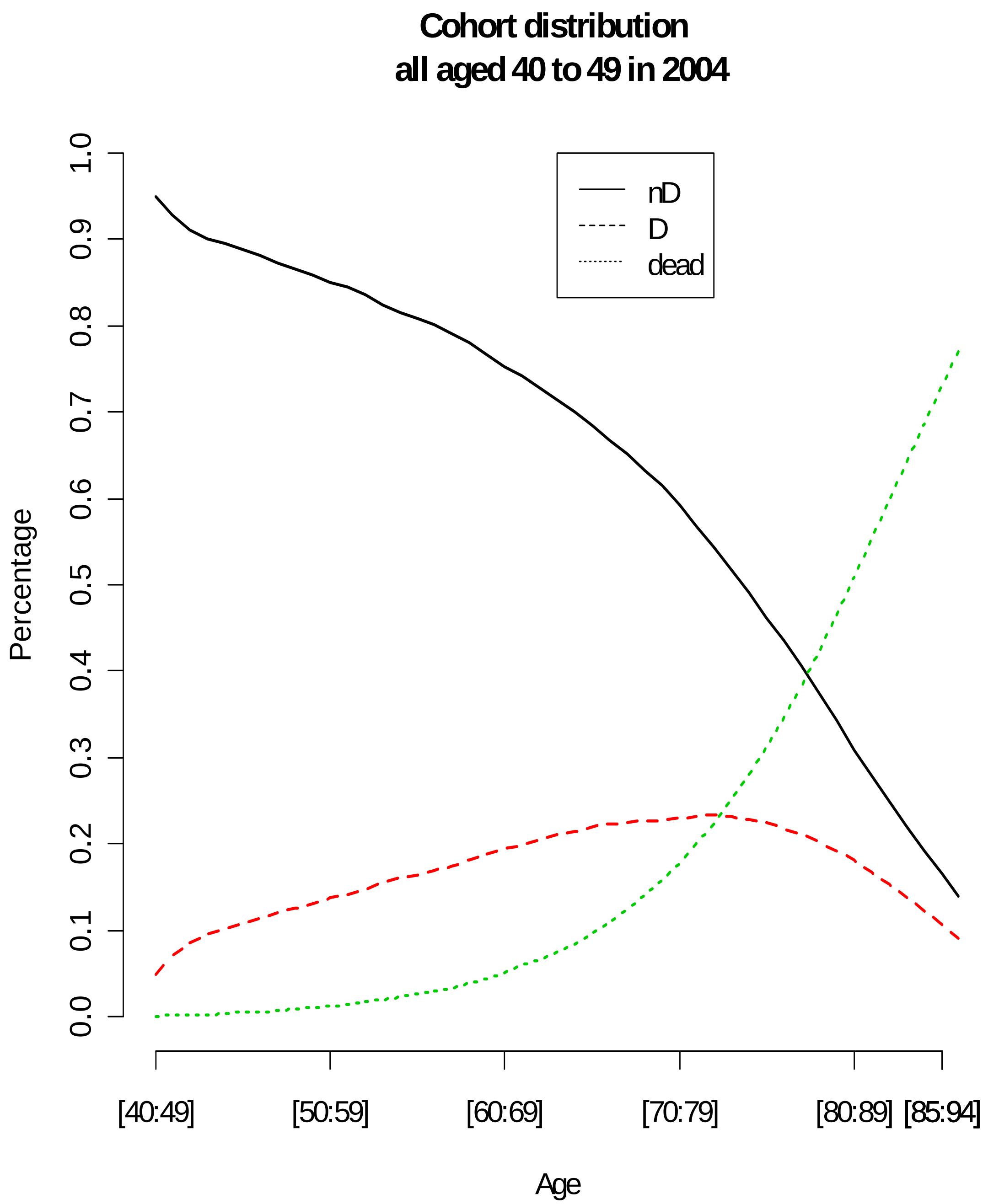
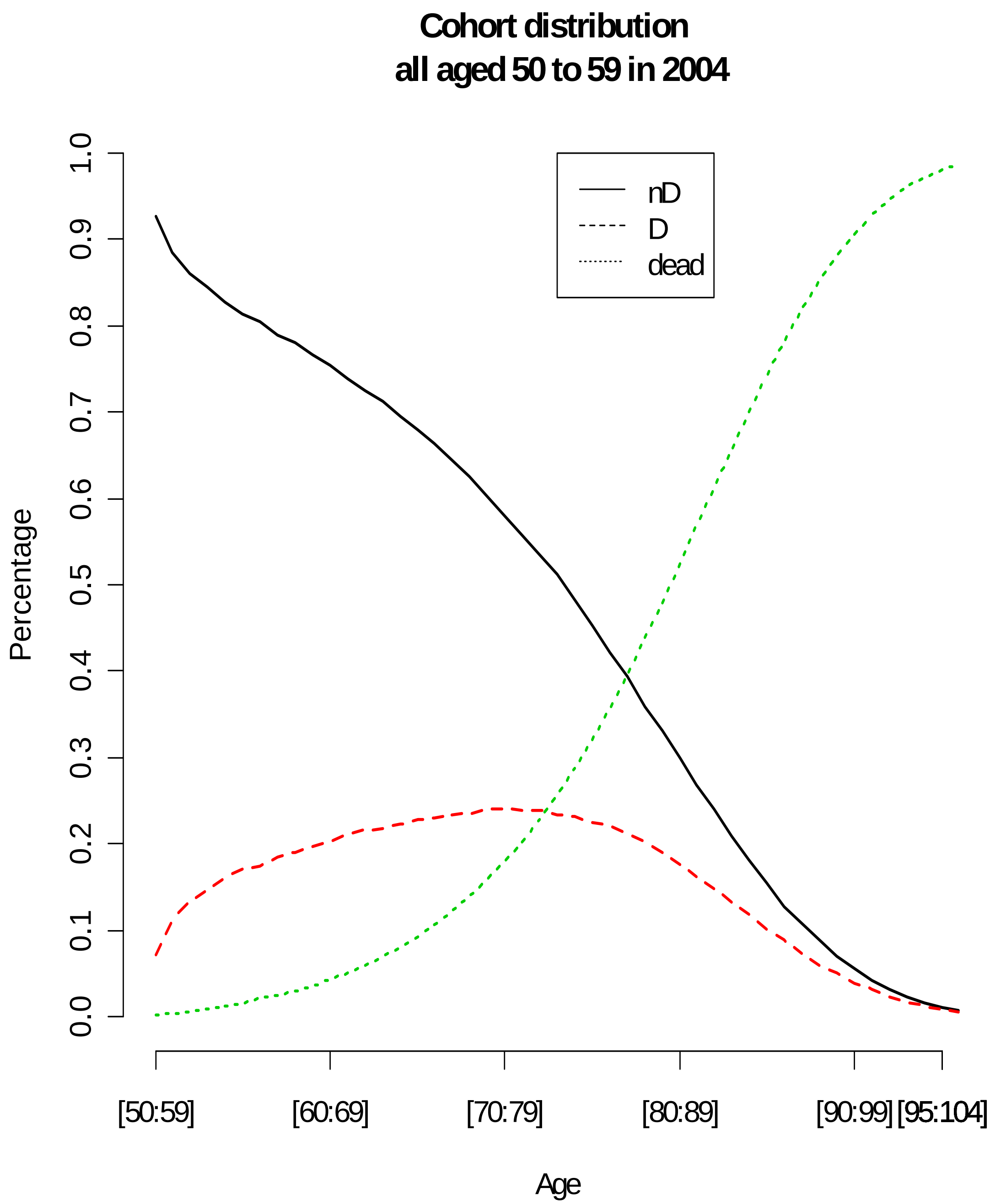


Figure 45 Trends in disability status, intervention scenario, total cohort age 50-59



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