

Estimated public health gains from smokers in Germany switching to risk-reduced alternatives: Results from population health impact modelling by socioeconomic group

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Abstract

Background

Previously, we estimated the impact of introducing heat-not-burn products and e-cigarettes in Germany between 1995 and 2015 on mortality from the four main smoking-related diseases in men and women aged 30–79 years. Deaths would have reduced by 216,650 (from 852,357 for continued smoking) had everyone quit smoking in 1995 and by 39,818 – 179,470 had one or both of heat-not burn products and e-cigarettes been introduced and adopted to varying extents. Here, we report substantial mortality reductions separately in two socioeconomic groups (A = higher, B = lower) defined by income and education.

Methods

Modelling is essentially as before, with individuals of a given sex, age range and cigarette smoking distribution followed over time under a “Null Scenario” (reduced-risk products never introduced) and various “Alternative Scenarios” (reduced-risk products introduced), the individual product histories generated then allowing estimation of reductions in mortality for each Alternative Scenario compared to the Null Scenario. Here, however, individuals are subdivided into two socioeconomic groups with transition probabilities between product use groups varying by group as well as by sex, age and length of follow-up. The possibility of transitioning between socioeconomic groups is also allowed for.

Results

Where all cigarette smokers switch immediately, half to each new product, the drops in deaths were estimated as 60,081 in group A and 122,343 in group B, about 82% of the drops associated with immediate cessation (72,725 A, 147,684 B). Where the conversion was more gradual, the drops were about 35% of those from cessation (25,648 A, 52,652 B). Drops were about two times higher in B, because of their greater numbers, older age, and higher frequency of current smokers. Years of life saved were also higher (about 1.5 times) in B than A.

Conclusions

Methodological limitations would not have affected our conclusion that introducing these products in 1995 in Germany could have substantially reduced mortality in each group, with greater gains in B. While cessation is the best choice to reduce mortality, switching to reduced-risk products also provides substantial health gains. Encouraging lower socioeconomic group smokers who would otherwise continue smoking to fully switch to reduced-risk products could diminish smoking-related health inequalities.

Background

This is the second of two related papers on estimating the population health impact in Germany of introducing two types of reduced-risk products (RRP) – the heat-not-burn product (HnB) and the e-cigarette (ECig) – under various assumptions about the rate of product uptake. The paper also compares these estimates with those derived by assuming that the whole population ceased smoking cigarettes immediately. The first paper [1], henceforward referred to as our “companion paper”, took no account of the possibility that product use status, transition among product use status, and mortality might vary by socioeconomic group (SEG), a possibility which is allowed for in the current paper. (Note that we use the term “product use” to refer to the use of any of the three products – cigarettes, ECigs, or HnBs).

In Germany, smoking prevalence is higher in lower SEGs, as expressed by the level of education and income [2], and socioeconomic differences based on occupational classification have increased in recent years [3]. Smoking is believed to contribute to health-related inequalities between SEGs, for example, with regard to quality of life, morbidity, and mortality [4–6]. Lower success rates in quitting smoking in lower SEGs have been found to contribute to these differences [7–10]. Targeted smoking cessation interventions could help reduce social inequalities [11]. However, evidence of interventions that work among lower SEGs is open to question.

While the best option for smokers is to quit smoking, switching to RRP is an alternative possibility that may reduce their risk of disease and one we investigate here. As noted in our companion paper, there are a number of examples of how switching to RRP can work in real life. These include the use of snus in Sweden [12], ECigs in the United Kingdom (UK) [13], and HnBs in Japan [14] as well as the results shown in our companion paper on the use of ECigs and HnBs in Germany. Recent studies have also suggested that RRP like ECigs can aid smoking cessation [13, 15, 16] and they have become the most popular smoking cessation aid in Germany [17] and the UK [18]. The effect of ECigs on smoking cessation has recently been proposed to possibly narrow the health inequalities from smoking [19].

Our main objective is to estimate the population health impact, as measured by the drop in deaths (DD) and the years of life saved (YLS), of introducing RRP (ECigs and HnBs) in Germany on two different SEGs. We have investigated various assumptions about the rate of uptake and compared the estimates of DD and YLS with those derived by assuming that all smokers in Germany quit immediately.

As in our companion paper, we have used here a “hindcasting” approach in which individuals start in 1995, with a nationally representative distribution of cigarette smoking, and are then followed up until 2015. The hindcasting approach avoids uncertainty about the future and the need to take into account the effect on future mortality rates of factors such as medical progress and infectious disease epidemics.

By comparing Scenarios where RRP are or are not introduced, this approach generates estimates of the DD and the YLS associated with RRP introduction for the four main diseases known to be related to cigarette smoking – lung cancer (LC), chronic obstructive pulmonary disease (COPD), ischaemic heart disease (IHD), and stroke. In comparison with our companion paper, our present estimates are derived separately for two SEGs.

Methods

Outline of the approach used

The method used for estimating the population health impact of introducing an RRP in Germany, which involves a Prevalence (P-) component and an Epidemiologic (E-) component, is essentially unchanged from that used in our companion paper. However, instead of individuals of a given sex in the P-component starting with a nationally representative distribution of age group and cigarette smoking, they start with a representative distribution of age group, SEG, and cigarette smoking. Additionally, they are followed up by using sets of nicotine usage transition probabilities (TP) that vary by SEG as well as by sex, age, and length of follow-up. As before, individuals are followed up under the Null Scenario, where RRP are never introduced, and various Alternative Scenarios, where one or more RRP may be introduced. In building up each individual's tobacco product use history over the follow-up, allowance is also made for individuals to change between the higher (A) and lower (B) SEGs.

Given the tobacco histories by SEG and the number of deaths by disease and SEG, the methodology used in the E-component to estimate the DD and the YLS associated with RRP introduction is unchanged from that used in our companion paper. The estimation is based on the negative exponential model (NEM) and, as before, requires estimates of the relative risk (RR) and quitting half-life for each disease, and of the effective doses for current exclusive HnB use, current exclusive ECig use, and multiple product use, compared with that for current cigarette smoking (taken as one unit). Note that the estimates of RR, quitting half-life for each disease, and effective dose are taken to be independent of the SEG.

Common features of each simulation

As in the companion paper, each simulation involved the follow-up of 100,000 individuals, initially aged 10–79 years, in 1-year intervals from 1995, with the product use status of each member of the simulated population being estimated annually until the year 2015 (or the members reach an age of 79 years, after which they are no longer followed up). For each scenario described below, separate simulations were conducted for each sex.

Population at baseline

At baseline, each individual is randomly allocated to a year of age, then to an SEG, then to a cigarette smoking group (never, current, or former), and then, for former smokers, to an age of quitting.

The sex-specific age distributions used for 1995 are as in the companion paper.

The definition of SEG was based on a combination of net annual income and mean years of education, as described by Foreman et al. [20].

The sex- and age-specific distributions of the population by SEG for 1995 were taken from estimates for the year 2002, derived from the German Socioeconomic Panel [21]. Section 1 of Additional File 1 gives fuller details of how the higher and lower socioeconomic groups A and B were defined.

The sex-, age- and SEG-specific distributions of current and former smoking prevalence for individual years from 1995 to 2015 were derived from the same three sources as those in the companion paper [21–23], with only the estimates for 1995 being required for the baseline population. More details are given in Sect. 2 of Additional File 1.

For the baseline population in 1995, the sex-, age- and SEG-specific distributions of quit time for former smokers were taken from the 2002 estimates derived from the German Socioeconomic Panel [21]. As in the companion paper, the data for age groups 10–14 and 15–19 years were taken from United States (US) estimates [24]. Details are given in Sect. 3 of Additional File 1.

Table 1 presents the sex- and age-specific data on population size and percentage in each SEG as well as the sex-, age- and SEG-specific data on the prevalence of current and former smoking. Table 2 presents the distribution of quit time used. These data were used to assign the initial status of each member of the simulated population. As shown in Table 1, the percentage of the population in group A declined steadily with age from 40–44 years, and, while the overall numbers (for age 10–79 years) in SEG B exceeded that in A in both sexes, this excess was only evident from age 50 years. Because the percentage of the population in group B increased steadily with age, the members in B overall (for age 10–79 years) were older than those in A (men by 3.85 years and women by 8.44 years). Among men, the prevalence of current smoking was greater in B than A, much more so at age 20–49 years than at older ages, with the overall difference between the two groups for age 10–79 years being by 6.69 percentage points (42.17% vs. 35.48%). Among women, the prevalence of current smoking was also much greater in B than A at age 20–49 years; however, the difference was reversed at older ages, so that, for age 10–79 years, the prevalence was very similar by SEG (25.95% in A and 26.67% in B). The overall prevalence of former smoking varied little by SEG in men, being 23.21% in A and 23.96% in B; but, in women, the prevalence was higher in A than in B (19.58% vs. 9.78%). The mean age was, as expected, higher in former smokers. The mean age was similar in A and B for current smokers but greater in B for former smokers.

Table 1
Data on population, proportion by SEG and smoking prevalence in Germany in 1995^a

Sex	Age (years)	Population (hundreds)	% in SEG A	% in SEG B	% current smokers		% former smokers	
					SEG = A	SEG = B	SEG = A	SEG = B
Men	10-14	23,112	50.00	50.00	6.12	6.12	0.00	0.00
	15-19	21,921	50.00	50.00	26.62	26.62	3.50	3.50
	20-24	24,908	41.42	58.58	48.85	61.65	6.41	18.75
	25-29	35,543	51.15	48.85	46.66	62.13	10.20	15.07
	30-34	37,604	59.96	40.04	44.92	62.39	14.82	13.05
	35-39	34,006	55.82	44.18	43.64	62.15	20.03	12.67
	40-44	29,154	56.12	43.88	42.96	62.47	26.44	13.43
	45-49	25,049	51.81	48.19	40.23	57.05	32.25	21.05
	50-54	27,482	45.32	54.68	35.47	44.43	38.60	31.52
	55-59	29,221	40.73	59.27	26.90	30.12	45.10	39.24
	60-64	20,582	36.66	63.34	18.65	22.09	49.78	42.61
	65-69	18,087	31.95	68.05	16.81	19.45	52.09	45.88
	70-74	12,280	29.04	70.96	13.75	14.92	52.90	49.50
	75-79	5,812	28.72	71.28	9.90	9.93	52.44	53.37
10-79	344,761	47.80	52.20	35.48	42.17	23.21	23.96	
Pop (00 s)	10-79	344,761	164,798	179,763	58,463	75,896	38,258	43,122
Mean age	10-79	40.92	38.91	42.76	37.82	39.52	49.93	53.82
Women	10-14	21,928	50.00	50.00	5.39	5.39	0.00	0.00
	15-19	20,788	50.00	50.00	19.73	19.73	0.16	0.16
	20-24	23,618	48.57	51.43	27.85	51.33	22.96	1.96
	25-29	33,241	57.39	42.61	30.24	51.30	21.54	8.05
	30-34	34,681	61.41	38.59	32.03	51.23	21.85	12.69
	35-39	31,271	63.68	36.32	33.05	50.82	23.53	15.94
	40-44	27,580	60.62	39.38	33.87	51.95	28.09	17.78
	45-49	24,142	50.59	49.41	31.01	41.55	25.84	18.09
	50-54	26,958	40.67	59.33	25.69	28.72	20.30	14.89
	55-59	29,511	39.71	60.29	19.18	18.52	17.03	9.49
	60-64	21,703	29.16	70.84	15.75	10.96	19.77	6.50
	65-69	22,609	18.91	80.09	14.54	6.29	23.12	8.21
	70-74	21,886	16.77	83.23	12.46	3.33	21.46	10.04
	75-79	12,226	17.95	82.05	10.52	2.26	16.35	12.74
10-79	352,142	45.78	54.22	25.95	26.67	19.58	9.78	
Pop (00 s)	10-79	352,142	161,201	190,941	41,829	50,930	31,559	18,674
Mean age	10-79	43.25	38.47	47.29	38.1	38.74	41.52	51.54

^aSources used: See text. Data on the distribution by SEG were for 2002 but taken to apply to 1995.

SEG = socioeconomic group defined based on education and income, with group A having the higher, and B the lower socioeconomic status. In the absence of available data, those aged 10-14 and 15-19 years were assumed to be equally divided between the two groups.

Table 2
Distribution of quit time^a by SEG in Germany in 1995

Sex	Age (years)	SEG = A Distribution of quit time (years) ^b						SEG = B Distribution of quit time (years) ^b					
		<1	1–2	3–5	6–10	11–20	21+	<1	1–2	3–5	6–10	11–20	21+
Men	10–14	99.9	0.1	0	0	0	0	99.9	0.1	0	0	0	0
	15–19	69.4	30.6	0	0	0	0	69.4	30.6	0	0	0	0
	20–24	38.7	29.8	31.5	0	0	0	51.1	41.7	7.2	0	0	0
	25–29	10.7	33.2	47.5	5.4	3.2	0	41.8	23.3	34.8	0	0	0
	30–34	13.7	49.1	21.2	11.8	4.2	0	19.5	36.7	14.2	7.6	22.0	0
	35–39	12.2	16.2	17.8	26.5	23.7	3.5	29.4	22.3	12.6	22.2	13.6	0
	40–44	10.7	14.2	10.7	16.5	40.5	7.3	19.1	15.3	12.3	22.7	26.3	4.4
	45–49	15.7	10.7	14.3	14.5	39.1	5.8	14.2	18.7	7.0	17.0	30.4	12.7
	50–54	5.8	8.3	10.7	14.5	41.8	18.9	9.1	13.2	23.9	13.8	22.9	17.2
	55–59	3.3	6.7	2.7	13.0	25.2	49.0	4.2	11.2	11.4	17.8	27.2	28.1
	60–64	4.5	8.4	7.7	6.1	33.6	39.6	5.6	6.4	11.5	8.0	26.9	41.7
	65–69	3.4	3.6	3.4	10.2	23.4	56.0	5.2	4.9	3.5	16.6	29.2	40.6
	70–74	0	7.3	7.1	1.9	24.6	59.0	5.0	5.9	7.6	10.1	22.7	48.6
	75–79	0	2.3	0.8	10.4	19.2	67.1	4.6	0.6	0.4	11.4	25.0	57.9
	Women	10–14	99.9	0.1	0	0	0	0	99.9	0.1	0	0	0
15–19		60.2	39.8	0	0	0	0	60.2	39.8	0	0	0	0
20–24		44.9	35.3	18.4	1.4	0	0	32.0	28.4	37.6	2.0	0	0
25–29		46.3	32.0	13.9	0.1	7.7	0	20.0	23.6	33.9	22.6	0	0
30–34		9.8	26.3	30.6	28.3	5.0	0	29.0	14.9	19.1	26.0	11.2	0
35–39		11.2	23.0	19.6	18.2	28.0	0	10.2	28.9	11.9	29.5	19.5	0
40–44		12.6	13.4	13.7	13.2	36.0	11.1	25.6	15.1	6.4	13.3	14.8	24.7
45–49		7.3	9.2	10.8	12.7	41.1	19.1	8.5	22.1	8.1	13.0	37.3	11.0
50–54		10.3	9.5	12.2	7.9	34.8	25.2	12.0	12.1	4.2	24.8	32.4	14.5
55–59		7.8	4.8	7.2	13.5	13.0	53.8	25.8	2.3	6.6	11.6	36.1	17.5
60–64		6.1	6.8	7.3	17.6	15.1	47.0	12.3	0.9	10.3	17.1	32.3	27.1
65–69		0.8	27.2	10.3	2.0	14.1	45.5	8.8	8.5	14.9	13.1	21.1	33.7
70–74		0	15.6	0	0.7	35.3	48.3	9.1	8.8	9.2	6.7	22.5	43.8
75–79		0	12.8	0	14.5	12.6	60.1	6.4	3.1	23.6	18.8	28.2	19.9

^a Sources used: See text. Data on the distribution by SEG were for 2002 but are taken to apply to 1995.

^b The full data separate 1–2 years into 1 and 2 years, 11–20 years into 11–15 and 16–20 years, and 21+ years into 21–30, 31–40, and 41–50 years.

SEG = socioeconomic group defined based on education and income, with group A having the higher, and B the lower socioeconomic status.

Estimation of histories of smoking for the Null Scenario

The sex-, age- and SEG-specific TPs used in the P-component for developing the histories of smoking for the Null Scenario were derived as described in Additional File 2 and are shown in Table 3. To test the validity of the TPs, prevalences predicted by using these TPs were compared with the estimates for Germany derived as described above for years up to 2015.

Table 3
Monthly tobacco transition probabilities (per million) by SEG in the Null Scenario for Germany

SEG	Period (years)	Age (years)	Initiation (P _{NC})		Quitting (P _{CF})		Re-initiation (P _{FC})	
			Men	Women	Men	Women	Men	Women
A	1–5	10–14	4,296	3,462	2,446	1,454	1,166	695
		15–19	5,578	5,948	4,293	18,310	2,035	8,325
		20–24	2,560	2,712	4,631	2,808	2,193	1,337
		25–29	173	1,301	3,411	2,390	1,621	1,139
		30–34	516	638	3,695	2,532	1,755	1,207
		35–39	0	0	4,007	2,891	1,901	1,376
		40–44	0	0	3,569	2,089	1,696	997
		45–49	0	0	4,041	2,396	1,434	855
		50–54	0	0	5,040	3,463	1,184	504
		55–59	0	0	4,487	6,368	527	404
		60–64	0	0	2,153	6,226	256	305
		65–69	0	0	2,252	3,685	134	195
		70–74	0	0	2,673	3,020	79	125
75–79	0	0	2,673	3,020	79	125		
A	6–10	10–14	3,654	2,986	2,063	2,210	985	1,054
		15–19	4,816	4,256	7,804	14,719	3,660	6,766
		20–24	978	1,993	4,476	3,470	2,120	1,649
		25–29	320	967	4,047	3,044	1,920	1,448
		30–34	461	477	4,158	3,100	1,972	1,475
		35–39	0	0	4,044	3,056	1,919	1,454
		40–44	0	0	3,146	2,798	1,496	1,201
		45–49	0	0	3,751	3,440	1,333	1,059
		50–54	0	0	4,358	4,121	1,027	786
		55–59	0	0	3,865	5,097	455	495
		60–64	0	0	2,627	4,689	311	462
		65–69	0	0	2,680	3,966	159	364
		70–74	0	0	3,144	4,767	93	205
75–79	0	0	3,144	4,767	93	205		
A	11+	10–14	2,883	2,072	1,840	3,593	879	1,706
		15–19	4,438	3,679	14,553	12,981	6,681	5,999
		20–24	374	1,186	5,489	3,933	2,593	1,865
		25–29	463	573	5,296	3,823	2,503	1,815
		30–34	409	283	5,029	3,931	2,379	1,866
		35–39	0	0	4,385	3,091	2,078	1,470
		40–44	0	0	2,750	3,681	1,309	1,146

The first period relates to the 5 years starting in 1995, the second period to the 5 years starting in 2000, and the third period to the 10 years starting in 2005.

The monthly probabilities of transition (per million) among the three states N = never, C = current, and F = former, are described by P (probabilities) followed by two subscripts, the first representing the state changed from and the second the state changed to.

Note that RRP are not introduced in the Null Scenario.

SEG = socioeconomic group defined based on education and income, with group A having the higher, and B the lower socioeconomic status.

		Initiation (P _{NC})		Quitting (P _{CF})		Re-initiation (P _{FC})		
		45-49	0	0	3,376	5,215	1,085	694
		50-54	0	0	3,432	4,989	703	499
		55-59	0	0	3,139	4,394	318	436
		60-64	0	0	2,893	3,412	278	340
		65-69	0	0	3,015	4,064	142	203
		70-74	0	0	3,571	7,872	83	148
		75-79	0	0	3,571	7,872	79	125
B	1-5	10-14	4,296	3,462	2,446	1,454	1,166	695
		15-19	13,030	9,824	4,406	5,752	2,088	2,714
		20-24	5,277	2,470	964	3,630	461	1,724
		25-29	2,432	1,663	1,061	2,619	508	1,247
		30-34	778	723	1,251	1,770	599	845
		35-39	0	0	1,474	981	705	470
		40-44	0	0	2,506	1,935	595	319
		45-49	0	0	3,506	1,903	414	181
		50-54	0	0	3,733	1,789	220	128
		55-59	0	0	2,756	3,032	163	108
		60-64	0	0	2,859	7,788	84	70
		65-69	0	0	4,057	10,198	60	46
		70-74	0	0	5,292	14,584	39	32
		75-79	0	0	5,292	14,584	39	32
B	6-10	10-14	3,654	2,986	2,063	2,210	985	1,054
		15-19	9,469	10,212	3,177	9,730	1,511	4,537
		20-24	3,359	2,024	1,323	3,327	633	1,582
		25-29	1,179	1,197	1,238	2,250	592	1,073
		30-34	760	380	1,640	1,462	784	699
		35-39	0	0	1,954	937	933	449
		40-44	0	0	2,219	1,486	791	354
		45-49	0	0	2,907	1,588	684	189
		50-54	0	0	3,276	1,900	430	113
		55-59	0	0	2,947	2,848	316	84
		60-64	0	0	2,853	4,239	153	62
		65-69	0	0	3,824	4,840	101	35
		70-74	0	0	4,687	5,286	61	22
		75-79	0	0	4,687	5,286	61	22
B	11+	10-14	2,883	2,072	1,840	3,593	879	1,706
		15-19	6,837	11,864	1,340	17,133	640	7,807

The first period relates to the 5 years starting in 1995, the second period to the 5 years starting in 2000, and the third period to the 10 years starting in 2005.

The monthly probabilities of transition (per million) among the three states N = never, C = current, and F = former, are described by P (probabilities) followed by two subscripts, the first representing the state changed from and the second the state changed to.

Note that RRP's are not introduced in the Null Scenario.

SEG = socioeconomic group defined based on education and income, with group A having the higher, and B the lower socioeconomic status.

	Initiation (P _{NC})		Quitting (P _{CF})		Re-initiation (P _{FC})	
20–24	1,323	1,495	1,532	2,845	732	1,355
25–29	1,852	678	2,093	1,715	998	819
30–34	1,718	190	2,458	1,141	1,171	546
35–39	0	0	2,727	874	1,299	419
40–44	0	0	1,856	1,166	886	301
45–49	0	0	2,293	1,958	819	233
50–54	0	0	3,219	2,218	646	132
55–59	0	0	3,077	2,882	305	85
60–64	0	0	3,259	2,316	160	69
65–69	0	0	3,821	2,463	94	36
70–74	0	0	4,223	2,245	52	33
75–79	0	0	4,223	2,245	39	32
The first period relates to the 5 years starting in 1995, the second period to the 5 years starting in 2000, and the third period to the 10 years starting in 2005.						
The monthly probabilities of transition (per million) among the three states N = never, C = current, and F = former, are described by P (probabilities) followed by two subscripts, the first representing the state changed from and the second the state changed to.						
Note that RRP's are not introduced in the Null Scenario.						
SEG = socioeconomic group defined based on education and income, with group A having the higher, and B the lower socioeconomic status.						

Estimation of histories of product use for the Alternative Scenarios

In the companion paper, we had considered seven different Alternative Scenarios, numbered 1 to 7. Here, we only considered four Alternative Scenarios (1, 3, 6, and 7), with the original numbering being retained in order to facilitate comparison between this paper and our companion paper. The four Alternative Scenarios are described briefly below and in more detail in our companion paper.

1. Complete cessation: All current cigarette smokers in 1995 immediately stop smoking, with no further product use.

3. Complete switch to RRP's (50% HnB and 50% ECig): All current cigarette smokers in 1995 immediately switch, half to HnBs and half to ECigs, with subsequent initiation, re-initiation, and quitting only involving the new products.

In the two Alternative Scenarios that were termed 6 and 7 in our companion paper, the market shares of HnBs and ECigs in 2005 were assumed to be, respectively, 15.5% and 36.4% of the market share of cigarettes in 1995. Scenarios 6 and 7 vary only in the proportion of exclusive users of the two RRP's, i.e. RRP users who have entirely given up cigarette smoking.

6. Conversion Scenario: The assumed proportions of exclusive users rise to 84% for both HnBs and ECigs.

7. Full Conversion Scenario: The assumed proportions of exclusive users rise to 100% for both HnBs and ECigs.

As previously described, various constraints were applied in Alternative Scenarios 6 and 7 to ensure comparability with the TPs for the Null Scenario, and the only difference between the two Scenarios is in the assumed rate of switching between the products.

RRP's are not introduced in Alternative Scenario 1. For the other three situations, the effective doses assumed, as measures for product harmfulness, were, as in the companion paper, 0.2 for exclusive HnB, 0.05 for exclusive ECig use, and 0.417 for multiple product use, as compared to an effective dose of 1 for exclusive cigarette use.

The full set of Alternative Scenario TPs is presented in Additional File 3.

Factors affecting TPs

As in the previous paper, the option that would allow TPs to depend on previous product history was not used.

Transitions between SEGs

Table 4 presents the annual TPs used to allow transition among SEGs. The method of derivation is described in Additional File 4.

Table 4
Annual probabilities of transition among SEGs by sex and age

Age (years)	Transitions from A to B		Transitions from B to A	
	Men	Women	Men	Women
10–14	0.02	0.02	0.0522	0.0371
15–19	0.02	0.02	0.0164	0.0086
20–24	0.02	0.02	0.0719	0.0400
25–29	0.02	0.02	0.0533	0.0484
30–34	0.02	0.02	0.0559	0.0486
35–39	0.02	0.02	0.0586	0.0527
40–44	0.02	0.02	0.0615	0.0574
45–49	0.02	0.02	0.0415	0.0352
50–54	0.02	0.02	0.0371	0.0316
55–59	0.02	0.02	0.0667	0.0327
60–64	0.04	0.04	0.0541	0.0283
65–69	0.04	0.04	0.0505	0.0294
70–74	0.06	0.06	0.0379	0.0114
75–79	0.06	0.06	0.0379	0.0114

SEG = socioeconomic group defined based on education and income, with group A having the higher, and B the lower socioeconomic status.

Estimating RRs on the basis of product use histories

The estimates of RR and quitting half-life for each disease are as given in our companion paper. The United Nations data on population size and the WHO data on numbers of deaths from 1995 to 2015 are presented in our companion paper. On the basis of these data, the method of estimating the numbers of deaths and increase in death rates associated with smoking is essentially as described earlier [24].

The sex- and age-specific data on national population size and numbers of deaths in Germany from LC, COPD, IHD, and stroke for the combined SEGs are as given in the companion paper, and the sources are described there. SEG-specific estimates were obtained by multiplying these values by the proportions in the SEGs. Additional File 5 presents the mortality data by SEG.

An additional analysis

Differences in the estimated DD and YLS between SEG A and SEG B may arise both because of differences among SEGs in the prevalence of smoking habits, and in age distribution. To gain insight into which of these factors was most important, an additional analysis was run, the same as for Scenario 6, except that the prevalence of smoking habits assumed was that for SEGs A and B combined, rather than varying by SEG.

Results

The full results of the analyses are available in Additional File 6.

Figure 1 compares the never, current, and former smoking prevalence estimates for Germany by sex and SEG for age groups 40–44 and 60–64 years as simulated in the Null Scenario (broken lines) with the estimates derived as described in the Methods section (solid lines). The fit for these (and other) age groups is generally quite good, confirming the validity of our approach. The distributions for other age groups are shown in Additional File 6.

Figure 2 presents the simulated estimates of product usage in the Conversion Scenario by sex, age (40–44 and 60–64 years), year (1995, 2000, 2005, 2010, and 2015), and SEG. In 1995, the estimates for current, never, and former smoking are identical, as expected, to those in the Null Scenario shown in Fig. 1. The main difference between Figs. 1 and 2 is in the distribution of current product users, who all smoke cigarettes in the Null Scenario but are split into four groups in the Conversion Scenario. Thus, in both SEGs A and B, the prevalence of current exclusive cigarette smoking declines steadily over the period, while the prevalences of current exclusive HnB use and current exclusive ECig use increase. The sharper increase in the first 10 years reflects the higher assumed uptake of ECigs.

More details for Scenarios 6 and 7 are shown in Additional File 6.

For all Alternative Scenarios, Additional File 7 summarizes, by SEG, the current product use distribution in 2005, overall current product use in 2010, and drop in the percentage of current product use in 2010. As expected (from the assumptions described earlier), there were no current product users at all in Scenario 1, and the total proportion of current product users in Scenarios 3, 6, and 7 were essentially the same, with the variation among these Scenarios being only in the distribution of the four current product use groups.

Table 5 presents the estimated DDs at ages 30–79 years over the whole follow-up period in all four Scenarios. The estimates were generated by using the P-component of PHIM and are shown by disease, for the four diseases combined, and by SEG (A, B, and A + B). The results are expressed both as numbers and percentages of all the smoking-related deaths from the four causes studied.

Table 5
Drop in deaths by SEG over the whole follow-up period in Germany in the four Alternative Scenarios (Sc 1, 3, 6, and 7)

SEG	Sc	Sex/Scenario	DD (n)					DD (%)				
			LC	IHD	Stroke	COPD	All four diseases	LC	IHD	Stroke	COPD	All four diseases
MEN												
A	1	Complete cessation	15,711	30,736	5,313	4,303	56,062	14.85	53.81	49.02	18.65	28.48
	3	Complete switch to RRP (50% HnBs, 50% ECigs)	12,721	25,390	4,519	3,676	46,305	12.02	44.45	41.70	15.93	23.53
	6	Conversion Scenario	4,904	10,498	1,979	1,625	19,007	4.64	18.38	18.26	7.04	9.66
	7	Full Conversion Scenario	5,197	11,221	2,099	1,701	20,218	4.91	19.64	19.37	7.37	10.27
B	1	Complete cessation	31,383	56,530	10,692	9,710	108,315	12.41	44.27	46.20	15.94	23.31
	3	Complete switch to RRP (50% HnBs, 50% ECigs)	25,538	46,790	9,104	8,280	89,713	10.10	36.64	39.34	13.60	19.31
	6	Conversion Scenario	10,059	19,516	4,077	3,605	37,256	3.98	15.28	17.62	5.92	8.02
	7	Full Conversion Scenario	10,549	20,353	4,249	3,766	38,918	4.17	15.94	18.36	6.18	8.38
A + B	1	Complete cessation	47,094	87,266	16,005	14,013	164,377					
	3	Complete switch to RRP (50% HnBs, 50% ECigs)	38,259	72,180	13,623	11,956	136,018					
	6	Conversion Scenario	14,963	30,014	6,056	5,230	56,263					
	7	Full Conversion Scenario	15,746	31,574	6,348	5,467	59,136					
WOMEN												
A	1	Complete cessation	6,703	5,841	2,592	1,527	16,663	23.66	55.38	51.42	24.18	33.17
	3	Complete switch to RRP (50% HnBs, 50% ECigs)	5,395	4,867	2,210	1,303	13,776	19.04	46.15	43.85	20.63	27.42
	6	Conversion Scenario	1,834	1,799	864	506	5,003	6.47	17.05	17.15	8.01	9.96
	7	Full Conversion Scenario	1,997	1,958	934	541	5,430	7.05	18.56	18.52	8.56	10.81
B	1	Complete cessation	15,980	13,209	5,264	4,916	39,369	20.66	45.87	51.20	23.60	28.68
	3	Complete switch to RRP (50% HnBs, 50% ECigs)	12,929	11,056	4,467	4,178	32,630	16.71	38.39	43.45	20.06	23.78
	6	Conversion Scenario	4,898	4,493	1,934	1,804	13,129	6.33	15.60	18.81	8.66	9.57
	7	Full Conversion Scenario	5,146	4,682	2,028	1,878	13,734	6.65	16.26	19.73	9.02	10.01
A + B	1	Complete cessation	22,683	19,050	7,856	6,443	56,032					
	3	Complete switch to RRP (50% HnBs, 50% ECigs)	18,324	15,923	6,677	5,481	46,406					
	6	Conversion Scenario	6,732	6,292	2,798	2,310	18,132					
	7	Full Conversion Scenario	7,143	6,640	2,962	2,419	19,164					
COPD = chronic obstructive pulmonary disease, DD = Drop in deaths, ECig = e-cigarette, HnB = heat-not-burn, IHD = ischaemic heart disease, LC = lung cancer, Sc = Scenario code, SEG = socioeconomic group defined based on education and income, with group A having the higher, and B the lower socioeconomic status.												

The DDs in the Conversion Scenario are also shown by sex, disease, and SEG over the whole follow-up period in Fig. 3.

The pattern of results in each SEG is similar to that described in our companion paper, with the largest DDs in both sexes being in Scenarios 1 and 3 and smaller DDs seen in Scenarios 6 and 7, where the switch to RRP is gradual. In both sexes, larger DDs are seen for IHD (particularly in men) and LC than for COPD or stroke, and the percentages of DDs in smoking-related deaths are the highest for IHD and stroke, which have shorter half-lives than LC and COPD.

The DDs are, in all Scenarios, substantially larger in SEG B than A, with SEG B being older, having more individuals, and a higher prevalence of product use. Thus, the combined DDs for both sexes in Scenarios 1, 3, 6, and 7 are, respectively, as follows: SEG A – 72,725; 60,081; 24,010; and 25,648 and SEG B – 147,684; 122,343; 50,385; and 52,652; in each case, the DD for B is about twice that for A. Although the DDs are higher for B than A, those expressed as a proportion of the DDs in Scenario 1 are similar. Thus, the DDs in Scenarios 3, 6, and 7 for the sexes combined represent, as a percentage of those in Scenario 1, respectively, 82.6%, 33.0%, and 35.3% in A and 82.8%, 34.1%, and 35.7% in B. The conclusion that DDs are markedly higher in B than A but the ratios of DDs by Scenario are similar in A and B also applies to the results for individual sexes and diseases.

It should be noted that, because the proportions by SEG vary substantially by age (as shown in Table 1), the ratio of DDs in B to A also shows marked variation by age. Thus, for Scenario 6, and for all four diseases combined, DDs in B, compared to A were 12% lower at age 40–44 (1266 vs. 1433), 34% higher at age 50–54 (5025 vs. 3758), 177% higher at age 60–64 (9355 vs. 3376) and 190% higher at age 70–74 (10117 vs 3492). A clear tendency for the ratio to rise with age was similarly evident in both sexes, in all four diseases, and in each Scenario (see Additional File 6).

The total DD in SEGs A and B combined can be regarded as an SEG-adjusted total, which can be compared with the unadjusted estimates in Table 4 in our companion paper. They are generally quite similar. Thus, the unadjusted DDs of 56,263 among men and 18,132 among women for the four diseases combined in Scenario 6 becomes 55,928 among men and 18,098 among women when adjusted. Similarly, the unadjusted and adjusted estimates are quite close when considering DDs by sex, disease, and Scenario.

Table 6 and Fig. 4 summarize the results for YLS by age 75 years by SEG for the four Scenarios over the whole follow-up period. As in the companion paper, the relative values for the different Scenarios are very similar to those of the DDs seen in Table 5. While the population health impact estimates are greater for SEG B than for SEG A, the difference is less marked for YLS than for DD, because the individuals in B are more likely to be older and retired and, therefore, have fewer expected years of life. Thus, for the sexes combined, the YLS in B exceed those in A by factors of 1.55, 1.55, 1.59, and 1.54, respectively, for Scenarios 1, 3, 6, and 7 (i.e., less than the factor of slightly over 2 seen for the difference in DDs between A and B). The ratios of YLS between the Scenarios are, however, very similar in A and B and quite similar to those noted above for DDs. Thus, for the sexes combined, the YLS values for Scenarios 3, 6, and 7, expressed as percentages of those in Scenario 1, are, respectively, 81.3%, 31.1%, and 33.8% in A and 81.0%, 31.9%, and 33.4% in B.

Table 6
Years of life saved (thousands) by age 75 years by SEG over the whole follow-up period in Germany in the four Alternative Scenarios (Sc 1, 3, 6, and 7)

SEG	Sc	Scenario	Men					Women				
			LC	IHD	Stroke	COPD	All four diseases	LC	IHD	Stroke	COPD	All four diseases
A	1	Complete cessation	194	563	87	36	880	116	114	55	19	305
	3	Complete switch to RRP (50% HnBs, 50% ECigs)	153	457	74	30	714	92	94	47	16	250
	6	Conversion Scenario	55	183	31	12	281	30	34	18	62	88
	7	Full Conversion Scenario	59	198	33	13	303	33	38	19	66	97
B	1	Complete cessation	312	855	142	66	1,374	175	175	77	37	465
	3	Complete switch to RRP (50% HnBs, 50% ECigs)	247	689	119	56	1,112	138	143	65	32	378
	6	Conversion Scenario	92	277	51	24	444	48	55	26	13	143
	7	Full Conversion Scenario	96	290	53	25	464	51	58	28	14	151

COPD = chronic obstructive pulmonary disease, ECig = e-cigarette, HnB = heat-not-burn, IHD = ischaemic heart disease, LC = lung cancer, Sc = Scenario code, SEG = socioeconomic group defined based on education and income, with group A having the higher, and B the lower socioeconomic status.

As in the companion paper, accounting for the increase in population size associated with the reduced mortality in the Alternative Scenarios relative to that in the Null Scenario made little difference to the estimated DDs. This is shown in the detailed results in Additional File 6.

In Scenario 6, the estimated DD for both sexes and all four diseases combined was 24,010 in SEG A and 50,385 in SEG B, an excess of 26,375 in B (see Table 5). In the additional analysis, which assumed that there was no variation in the prevalence of smoking by SEG, the estimates were 24,998 in A and 49,022 in B, an excess of 24,024 in B that was 91.1% of that for the original analysis. Corresponding percentages were 93.6% for men and 85.4% for women. Based on YLS, totals over sex and disease (in thousands) in our original analysis (see Table 6) were 369 in A and 587 in B, an excess of 218. In the additional analysis, these estimates were 395 in SEG A and 587 in SEG B, a difference of 163, which is 74.8% of that seen originally. For both DD and YLS, these results demonstrate that most of the excess mortality seen in SEG B was due to the age differences among the SEG groups, though differences in smoking habits also contributed. To be clear, smoking-related diseases, as we consider here, originate from smoking, not from age differences, which is why public health measures have duly focused on lowering smoking prevalence to curb the health consequences of consuming combustible cigarettes.

Discussion

To our knowledge, this is the first study to estimate the population health impact of introducing RRP in Germany by SEG. Depending on the Scenario, the health gains would have reached 34–83% of that from immediate smoking cessation, regardless of the SEG. For each of Scenarios 3, 6 and 7, the gains in the

lower SEG population (B) compared with those in the higher SEG population (A) would have been more than twice as high for DD and more than 1.5 times as high for YLS. Depending on the Scenario, these excess gains in B than in A corresponded to a greater DD by 27,004 to 62,262 and a greater YLS by 215,000 to 526,000.

In our companion paper, which took no account of the SEG, we estimated that, in Scenarios 1 (Complete cessation), 3 (Complete switch to RRP – 50% HnBs, 50% ECigs), 6 (Conversion), and 7 (Full Conversion), the DDs for the sexes combined and all four diseases combined would have been, respectively, 216,650; 179,470; 75,597; and 81,293. According to the results in Tables 5 and 6 in this paper, which did take into account the SEG, the corresponding estimates were quite similar (220,409; 182,424; 74,395; and 78,300, respectively) to those in our companion paper. Our results suggest that taking SEG into account had little effect on the overall estimated DDs. They also show that substantial DDs were seen in both SEG groups, A and B, with the drops being about twice as high in B as in A.

The estimates of population health impact in both SEGs are likely to be conservative for the three main reasons discussed in our companion paper – that deaths were only counted for four diseases, that only a 20-year follow-up period was considered, and that we failed to account for the possibility that cigarette smokers who took up HnBs and ECigs might subsequently be more likely to quit cigarettes than those who continued as exclusive smokers. We also note that the RRs we have used for current and former smoking (on the basis of published meta-analyses) are lower than those used by others (on the basis of specific studies) when estimating deaths attributable to smoking in Germany [25]. Using higher RR estimates would have increased our DD estimates. However, our estimates might be optimistic if the rates of uptake of HnBs and ECigs are lower than what we have assumed, or if, in fact, taking up HnBs and ECigs makes smokers less likely to quit or increases their cigarette consumption. There is little real-life evidence, however, that the latter is the case.

While there is mounting scientific consensus that RRP like ECigs and HnBs represent less risk than cigarettes [26, 27], there has been debate on whether smoking-related health inequalities between SEGs could be reduced by smokers switching to RRP [28]. Some studies have found more advantaged smokers to be more likely to use ECigs in the UK [29] or HnBs in Germany [30], whereas others have recently observed that ECigs might be helping disadvantaged smokers quit [19]. ECigs might have contributed to some of the highest UK smoking cessation rates so far, with parity across SEGs [31]. This suggests that ECigs worked as quitting aids for low SEG smokers previously not reached by conventional methods and can be explained by the high acceptability of RRP as substitutes for cigarettes, as witnessed from ECigs being the most popular quitting aids in the UK [18] and Germany [17, 32]. It is notable that conventional pharmacotherapies for smoking cessation are more commonly used in Germany by smokers with higher incomes [17, 32], thus possibly increasing health inequalities. The question whether this is linked to the affordability of pharmacotherapies or to factors related to education has not been conclusively answered. While a recent study found higher income of German smokers to be associated with more frequent use of pharmacotherapies, neither income nor education affected quit success [32]. On the other hand, use of the most popular quitting aid ECigs was not associated with income or education, underlining that RRP could be a promising addition to public health strategies aimed at providing equal chances for smokers from different SEGs to exit out of cigarettes [32].

Data from several individual countries have shown that lower social grades and level of education are significantly linked to inaccurate harm perception of ECigs [26, 33]. Currently, 61% of German smokers falsely perceive ECigs as equally harmful or more harmful than cigarettes, with only 5% correctly perceiving them as much less harmful [34]. Given that ECigs are more likely to be used for smoking cessation if they are perceived as less harmful than cigarettes [35], misperceptions might well be discouraging many cigarette smokers from trying RRP. Improving current perception is particularly important for disadvantaged populations of smokers, such as those in lower SEGs, who could benefit more from RRP as a harm reduction tool.

Uptake of RRP by smokers is also affected by other factors such as taxation [36], affordability [37], moral concerns around addiction [38], and consumer choice regarding ECig flavors [39]. To reduce smoking-related health inequalities, an integrated strategy has been proposed which combines targeted cessation programs, tobacco control measures, and educational media campaigns, all applied within wider attempts to address inequalities in health [9]. Clear communication of relative risks, delivered through targeted public health educational campaigns, could help realize the potential of RRP for harm reduction among lower SEGs.

The strengths of our study include the use of nationally representative data and the hindcasting approach, which helps avoid problems in accounting for the unknown future effects of other factors, such as medical advances, infections, wars, and global warming, on future death rates. Our methodology also allows the population health impact of RRP introduction to be estimated under a variety of different assumptions.

There are, however, a number of potential limitations that need to be considered in interpreting our estimates. Issues regarding our failure to consider other sources of nicotine or environmental tobacco smoke, the possible limitations in our negative exponential model, the choice of effective doses, limiting our attention to deaths at ages 30–79 years, and the choice of appropriate uptake rates of HnBs and ECigs have been discussed in our companion paper and are not considered further here. Also failure to take into account the reduced mortality in the Alternative Scenarios compared to that in the Null Scenario was shown to have very little effect on the results.

Some issues specifically relating to estimation of population health impact by SEG are, however, worth consideration. One is that the age- and sex-specific prevalence data for current and former smoking in Germany by SEG was only available for 2 years (2002 and 2012); therefore, annual data had to be estimated by a combination of interpolation/extrapolation and smoothing (as described in Additional File 1). More detailed source data might have led to some revision of our estimates, but it seems unlikely that they would have made much difference, given that the adjustment for SEG had little effect on the unadjusted estimates.

Similar considerations apply to the derivation of TPs by SEG in the Null Scenario, which, as described in Additional File 2, are calculated based on the distribution of smoking habits in the same birth cohort 5 years apart. Errors in the distributions would have led to errors in the estimated TPs, and inspection of the TPs in Table 3 shows that though the general patterns by SEG and age look plausible, there are a few exceptions. For example for SEG A period 1–5

years, the estimated initiation rates in men rise between ages 25–29 and 30–34 years, while at age 15–19, but not at other ages, quitting and re-initiation rates were much higher in women than men. Given that the changes in the distribution of smoking habits over time generated by the model using the TPs matched quite well observed distributions in Germany, it is unlikely that any further attempt to improve estimation of these TPs would have materially affected our conclusions.

Another issue is that data on transfer between SEG groups A and B were not available for Germany, and the data used here (as described in Additional File 4) were derived partly from the current smoking prevalence rates in the USA coupled with assumptions about the age-specific level of transfer from A to B. In fact, weaknesses in these data seem unlikely to be very relevant because re-running the analyses for Alternative Scenario 6 by disallowing the possibility of transfer had little effect on the overall estimates and only slightly reduced the estimated DDs shown in Table 5 (19,007 [A men]; 37,256 [B men]; 5,003 [A women]; and 13,129 [B women] to 18,738 [A men]; 37,193 [B men]; 4,962 [A women], and 12,999 [B women]). (Detailed results not shown.)

One other issue relates to how we classified the SEGs. As noted earlier, our classification used a previously described standard method [20] based on a combination of net annual income and mean years of education. Using methods that also took occupation into account or classified individuals into more than two groups would have been possible, but it is doubtful that it would have affected the conclusion that switching to RRP would have reduced the risk and been more beneficial in groups that smoke more.

A further issue is that, for any given year, disease, sex, or age group, the estimated number of deaths by SEG was derived from the reported number for the combined SEG by multiplying this number by the estimated proportions in A and B for that year, sex, and age group. This assumes that the mean risk of death is identical in SEG groups A and B. While data are available from the NEM on the average RR (relative to never smokers) in each SEG group, no data are available on the absolute risk separately in A and B and, therefore, a precise test of this assumption is not possible. However, some idea of the potential effect of allowing for variation in risk by SEG can be gained from an example based on the data for men and all diseases combined. Overall there were 1,901,972 deaths, and, if one assumes that the risks per individual in A and B are the same, we can estimate on the basis of age-specific proportions in A and B that there would be 542,783 deaths in A and 1,359,189 in B. If, on the other hand, one assumes that the average risks in B are twice those in A, one can readily calculate that the deaths would be split as 316,562 in A and 1,585,410 in B. In Alternative Scenario 6, the assumed 542,783 deaths in A would drop by 19,007 (3.51%) and the 1,359,189 deaths in B would drop by 37,256 (2.74%), a total DD of 56,263. On the basis of these percentages and the revised numbers of deaths in A and B, the 316,562 deaths in A would drop by 11,085 and the 1,585,410 deaths in B by 43,437, a total DD of 54,542. Thus, even with this quite extreme assumption, the total DD is not changed that much, and there are still substantial DDs in both A and B, though the DD in A is decreased and that in B is increased.

Overall, our results clearly demonstrate that increasing uptake of HnBs and ECigs would reduce the adverse population health impact of cigarette smoking in both SEG groups A and B. They also show that adjustment for SEG makes little difference to the estimated impact in the total population.

Conclusions

Our population health impact model showed that introducing RRP (ECigs and HnBs) into the tobacco market in Germany in 1995 would have resulted in substantial reductions in mortality from the four main smoking-related diseases over the following 20 years in both SEGs studied here. Depending on the Scenario chosen, these gains would have amounted to 31–82% of those achieved by immediate smoking cessation, the optimal Scenario. Considering that only 19% of German smokers even attempt cessation each year and few succeed [17], tobacco harm reduction by fully switching to RRP represents a public health opportunity currently not exploited in Germany.

While our model predicts similar percentage reductions in mortality in both SEGs, the total predicted reductions were greater in the lower SEG, B, by about 2-fold for DDs and about 1.5-fold for YLS, because of individuals in B being somewhat more numerous, of a higher average age (as the proportion of the population in B increases markedly with age), and more commonly current smokers (evident especially among men and at younger ages). These greater reductions in mortality in B correspond to an extra 27,000 to 62,000 DDs and 215,000 to 526,000 YLS, depending on whether Scenarios 3, 6 or 7 are considered.

Our results thus suggest that inclusive access to RRP, i.e. access to acceptable, affordable products as well as comprehensible relative risk information about them, could diminish smoking-related health inequalities between SEGs. A public health approach that encourages low SEG smokers who would otherwise continue to smoke to switch to RRP could synergize with tobacco control measures targeted at lower SEGs to further reduce such inequalities.

Abbreviations

A = higher socio-economic group, B = lower socio-economic group, COPD = chronic obstructive lung disease, DD = drop in deaths, E- component = epidemiologic component, E-cig = electronic cigarette, HnB = heat-not-burn, IHD = ischaemic heart disease, LC = lung cancer, NEM = negative exponential model, P- component = prevalence component, RRP = reduced risk product, SEG = socio-economic group, TP = transition probability, UK = United Kingdom, US = United States, YLS = years of life saved.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

All data generated or analyzed during this study are included in this published article and its supplementary information files.

Competing interests

RR and AKN are employees of Philip Morris International. SD was an employee of Philip Morris International at the time the work was carried out. AK, EB, PNL and JSF were contracted consultants for the project and paid by Philip Morris International.

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Authors' contributions

The work described here was conceived by RR, SD, AKN and PNL. Some of the data required was extracted by AK and EB. The analyses were run by JSF, RR and SD, and checked by PNL. The manuscript was drafted by PNL, with contributions by AKN, and developed following comments by RR, SD, EB and JSF. All authors read and approved the final manuscript.

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Figures

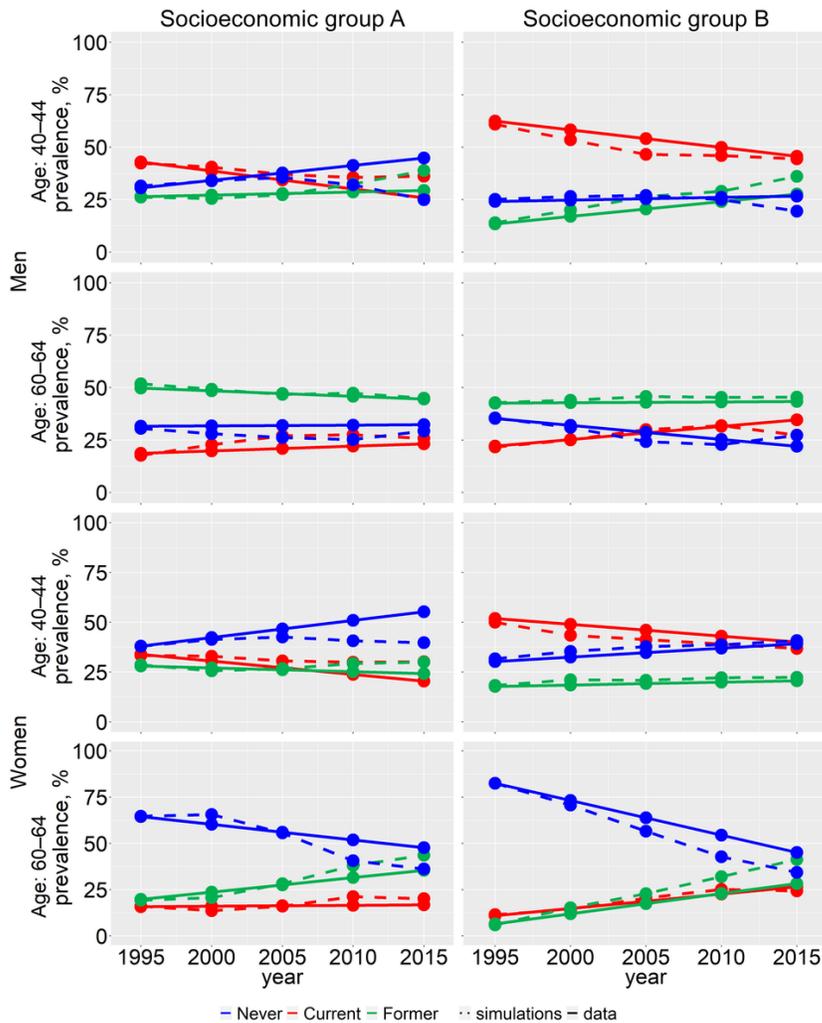


Figure 1

Comparison of Null Scenario and derived estimates of current smoking prevalence by sex, age, SEG, and year of follow-up.

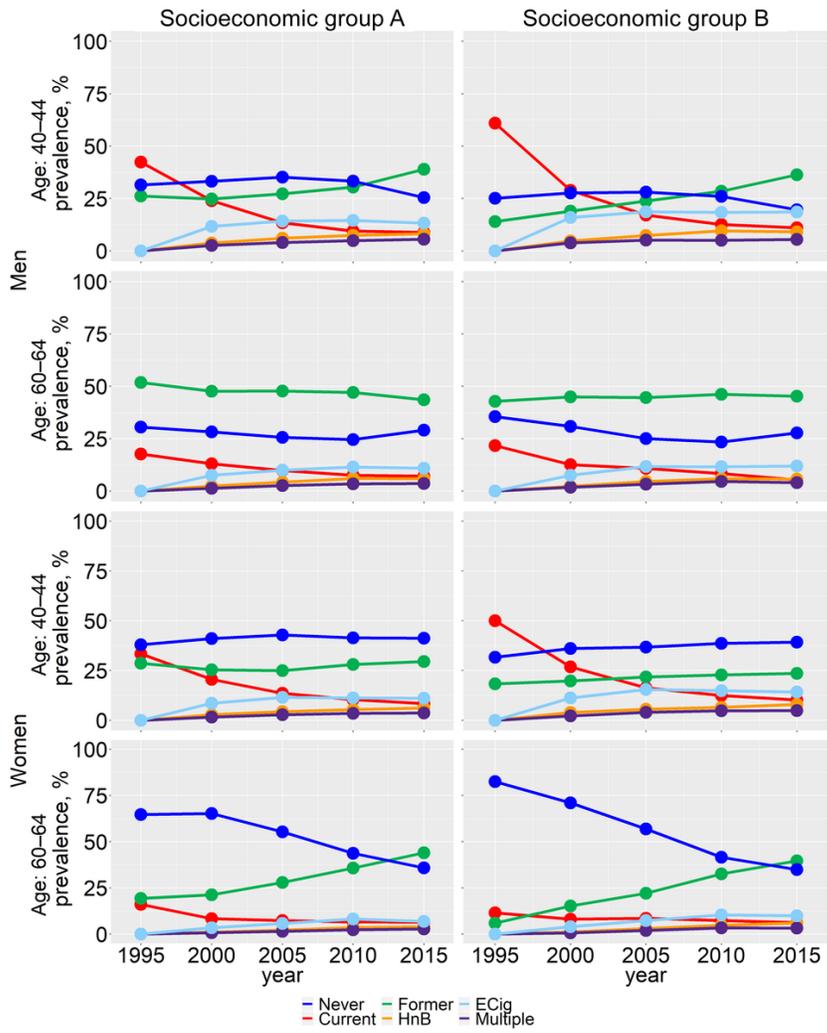


Figure 2
Nicotine usage in the Conversion Scenario.

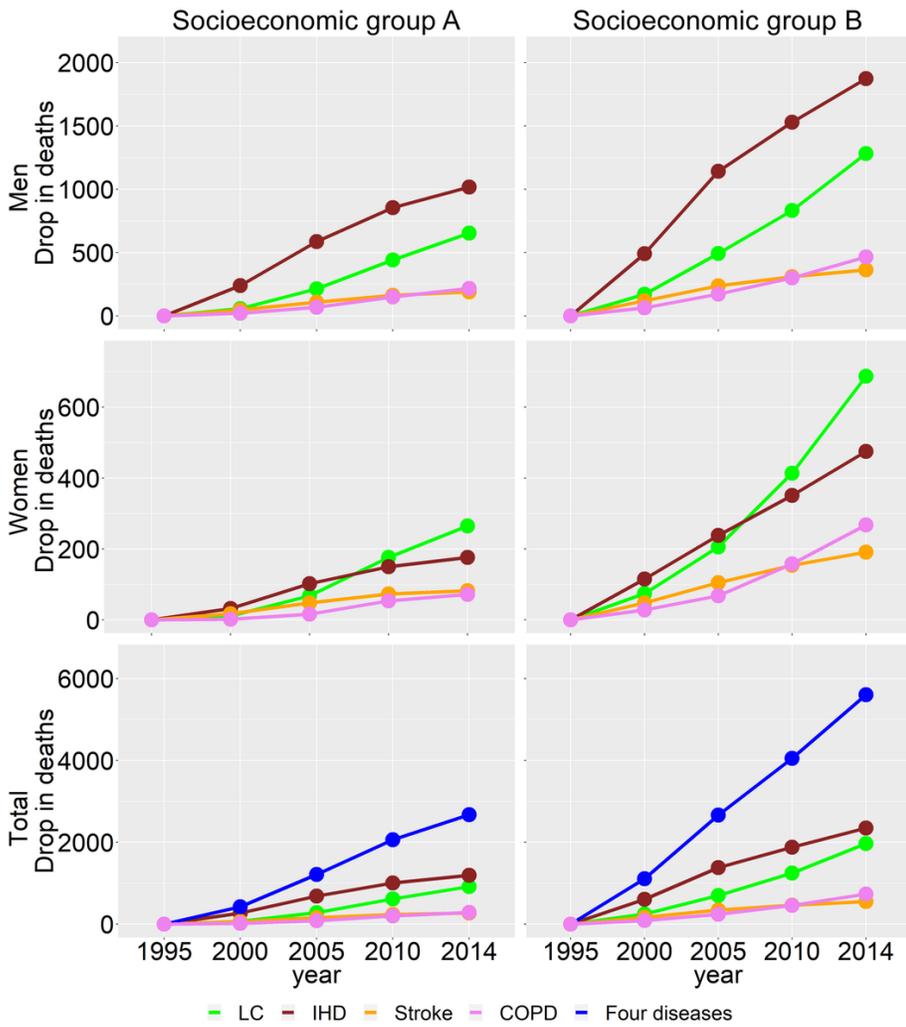


Figure 3

DDs in the Conversion Scenario over the whole follow-up period.

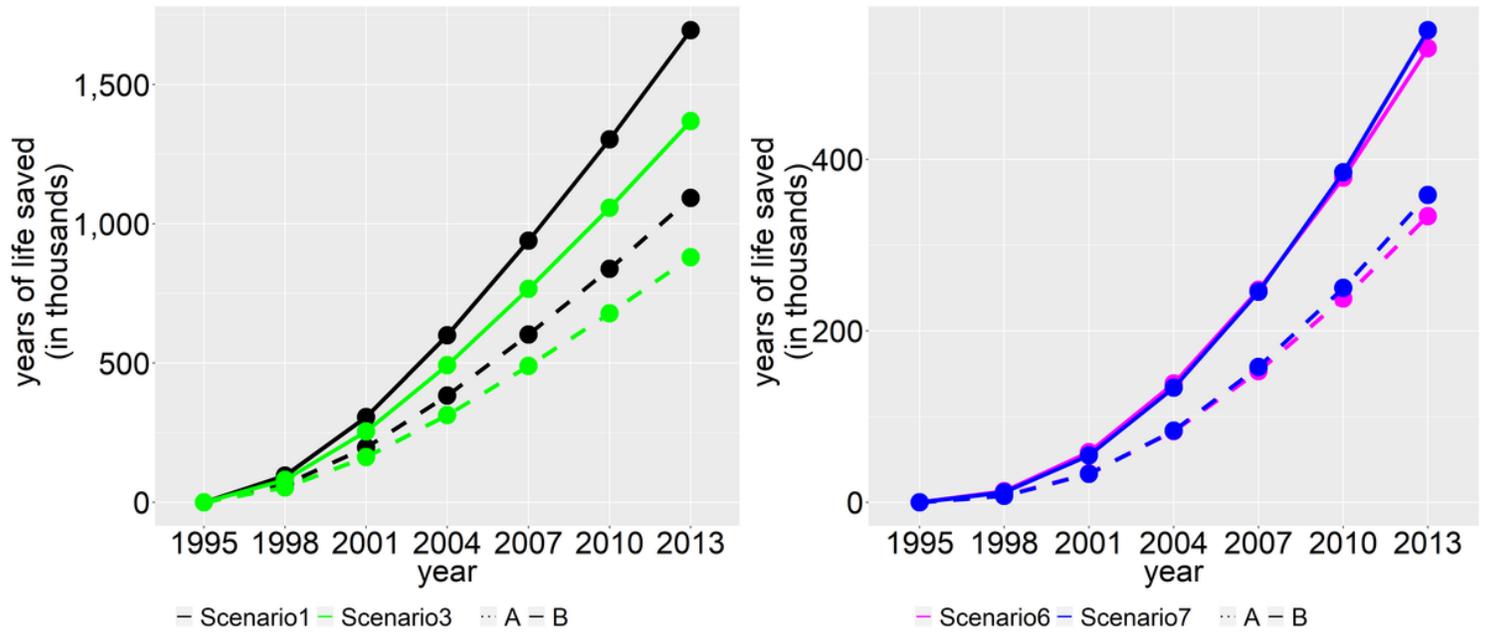


Figure 4

YLS by Scenario and SEG over the whole follow-up period

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