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Estimated Public Health Gains From Smokers in Germany Switching to Reduced-Risk Alternatives: Results From Population Health Impact Modelling by Socioeconomic Group *

by

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SUMMARY

Background: We previously estimated the impact of introducing heat-not-burn products and e-cigarettes in Germany on smoking-related disease mortality in men and women aged 30–79 years between 1995 and 2015. Here, we estimate the impact by socioeconomic group.
Methods: Individuals with a defined baseline cigarette smoking distribution were followed under a "Null Scenario" (no reduced-risk products) and "Alternative Scenarios" (reduced-risk products introduced). Transition probabilities allowed estimation of annual product use changes, with individual product histories used to estimate reductions in deaths and life-years lost. Here, however, individuals were classified into two socioeconomic groups defined by income and education, with allowance for variation by group in initial smoking prevalence and the probability of changing product use, or of changing socioeconomic group.
Results: With no allowance for socioeconomic group, deaths would have reduced by 217,000 (from 852,000 for continued smoking) had everyone immediately ceased smoking in 1995 and by 40,000 to 179,000 had one or two types of reduced-risk products – the heat-not-burn product and the e-cigarette – been adopted by smokers to varying extents. With such allowance, we estimate substantial drops in each socioeconomic group. Where all cigarette smokers switched immediately, half of them to heat-not-burn products, half to e-cigarettes, the estimated drops in deaths were 60,000 in group A (higher socioeconomic group) and 122,000 in group B (lower), about 82% of the drops associated with immediate cessation (73,000 in A and 148,000 in B). With more gradual conversion, the drops were 26,648 in A and 53,000 in B, about 35% of those from cessation. The drops in deaths and life-years saved were about 2 and 1.5 times higher in group B, respectively, associated with its greater numbers, older age, and higher smoking prevalence. The estimated reductions would increase upon considering more diseases, a wider age range, or longer follow-up. Methodological limitations would not

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affect the conclusion that introducing these products in 1995 in Germany could have substantially reduced deaths and life-years lost in both groups, more so in B.
Conclusions: Although cessation is optimal for reducing mortality, switching to reduced-risk products also provides substantial health gains. A public health approach encouraging lower socioeconomic group smokers to switch to reduced-risk products could diminish smoking-related health inequalities relative to continued smoking. [Contrib. Tob. Nicotine Res. 31 (2022) 52–67]

KEYWORDS

Smoking; public health; smoking-related disease; modelling; respiratory disease; cardiovascular disease; e-cigarettes; heat-not-burn products; socioeconomic group; Germany;

ZUSAMMENFASSUNG

Hintergrund: Zuvor haben wir die Auswirkungen der Einführung von Tabakerhitzern und E-Zigaretten zwischen 1995 und 2015 in Deutschland auf die Mortalität durch mit Rauchen assoziierte Krankheiten bei 30- bis 79-jährigen Männern und Frauen geschätzt. Hier schätzen wir die Auswirkungen nach sozioökonomischen Gruppen.
Methoden: Individuen mit einer zum Ausgangszeitpunkt definierten Verteilung des Zigarettenrauchens wurden in einem „Null-Szenario“ (keine Produkte mit geringerem Risiko) und in „alternativen Szenarien“ (Einführung von Produkten mit geringerem Risiko) nachbeobachtet. Übergangswahrscheinlichkeiten ermöglichten die Einschätzung der jährlichen Veränderungen in der Produktnutzung und individuelle Nutzungshistorien wurden herangezogen, um die Abnahme der Todesfälle und der verlorenen Lebensjahre zu schätzen. Hier wurden die Personen jedoch in zwei sozioökonomische, durch Einkommen und Bildung definierte Gruppen eingeteilt, wobei eine Veränderung der anfänglichen Raucherprävalenz und die Wahrscheinlichkeit eines Umstiegs auf ein anderes Produkt oder eines Wechsels in eine andere sozioökonomische Gruppe berücksichtigt wurden.
Ergebnisse: Ohne Berücksichtigung der sozioökonomischen Gruppe wäre die Zahl der Todesfälle um 217.000 (ausgehend von 852.000 bei fortgesetztem Rauchen) gesunken, wenn 1995 alle Raucher das Rauchen unverzüglich aufgegeben hätten, und um 40.000 bis 179.000, wenn Raucher eine oder zwei Arten von risikoreduzierten Produkten – Tabakerhitzer und E-Zigaretten – in unterschiedlichem Ausmaß angenommen hätten. Unter entsprechender Berücksichtigung schätzen wir erhebliche Rückgänge in beiden sozioökonomischen Gruppen. Wären alle Zigarettenraucher sofort umgestiegen, eine Hälfte von ihnen auf Tabakerhitzer, die andere Hälfte auf E-Zigaretten, hätten die Rückgänge der Todesfälle in Gruppe A (höhere sozioökonomische Gruppe) schätzungsweise bei 60.000 gelegen und in Gruppe B (niedrigere) bei 122.000, was etwa 82% der Rückgänge im Vergleich zu einem Szenario des sofortigen Rauchstopps entspricht (73.000 in A und 148.000 in B). Bei einem graduelleren Umstieg hätten die Rückgänge in A bei 26.000 gelegen und in B bei 53.000, etwa 35% der Rückgänge im Vergleich zum Rauchstopp-Szenario. Der Rückgang der Todesfälle bzw. die gewonnenen Lebensjahre waren in Gruppe B aufgrund der größeren Gruppe, des höheren Alters und der höheren Raucherprävalenz etwa 2 bzw. 1,5 Mal höher. Die geschätzten Abnahmen wären größer, wenn mehr Krankheitsarten, ein breiterer Altersbereich oder längere Nachbeobachtungszeiträume in Betracht gezogen würden. Methodologische Einschränkungen würden keinen Einfluss auf die Schlussfolgerung haben, dass die Einführung dieser Produkte 1995 in Deutschland die Todesfälle und die verlorenen Lebensjahre in beiden Gruppen, und besonders in B, erheblich verringert haben könnte.
Schlussfolgerungen: Obwohl der Rauchstopp die optimale Methode zur Reduktion der Mortalität ist, kann eine Umstellung auf Produkte mit geringerem Risiko ebenfalls einen erheblichen gesundheitlichen Nutzen bieten. Eine Strategie des Gesundheitswesens, die Raucher aus niedrigeren sozioökonomischen Gruppe dazu ermutigt, auf Produkte mit geringerem Risiko umzusteigen, könnte die durch Rauchen bedingten gesundheitlichen Ungleichheiten im Vergleich zum fortgesetzten Rauchen verringern. [Contrib. Tob. Nicotine Res. 31 (2022) 52–67]

RESUME

Contexte: Nous avons précédemment évalué l’impact que l’introduction de produits de tabac chauffé et de la cigarette électronique aurait eu sur la mortalité par maladie liée au tabagisme par cigarette en Allemagne chez des hommes et des femmes âgés de 30 à 79 ans entre 1995 et 2015. Dans cet article, nous évaluons cet impact en fonction du groupe socioéconomique.
Méthodes: Des sujets présentant un niveau de consommation de cigarettes déterminé lors de leur inclusion dans ce modèle ont été suivis soit selon un « Scénario Nul » (sans introduction de produits à risque réduit) soit selon plusieurs « Scénarios Alternatifs » (avec introduction de produits à risque réduit). Les probabilités de transition ont permis d’estimer les changements annuels en termes de produits utilisés ; l’historique des produits utilisés par chaque sujet a été utilisé pour estimer la réduction du nombre de décès ainsi que la réduction du nombre d’années de vie perdues. Cependant, dans cette analyse, les sujets étaient classés en deux groupes socioéconomiques définis en fonction de leurs revenus et de leur niveau de formation. La variation de la prévalence initiale du tabagisme selon le groupe et la probabilité d’un changement de produit ou d’un changement de groupe socioéconomique étaient prises en compte.
Résultats: Si tous les fumeurs avaient arrêté immédiatement de fumer en 1995, le nombre de décès aurait été diminué de 217.000 (par rapport à 852.000 décès en cas de poursuite du tabagisme) sans prise en compte de groupe socioéconomique. Cette diminution aurait été comprise entre 40.000 et 179.000 si les sujets avaient adopté, à divers degrés, un ou deux types de produits à risque réduit – le produit de tabac chauffé et la cigarette électronique. En tenant compte de ce facteur, nous estimons des baisses substantielles dans chaque groupe socioéconomique. Si tous les fumeurs avaient remplacé immédiatement la cigarette par l’un de ces nouveaux produits (produits de tabac chauffé pour la moitié d’entre eux et cigarette électronique pour l’autre moitié), la baisse estimée du nombre de décès aurait été de 60.000 dans le groupe A

(groupe socioéconomique supérieur) et de 122.000 dans le groupe B (groupe socioéconomique inférieur), soit environ 82% comparé à l'effet de l'arrêt immédiat du tabagisme (73.000 dans le groupe A et 148.000 dans le groupe B). En cas de conversion plus progressive, cette baisse aurait été de 26.000 dans le groupe A et de 53.000 dans le groupe B, soit environ 35% comparé à l'effet de l'arrêt du tabagisme. La baisse des décès et le nombre d'années de vie gagnées seraient respectivement environ 2 à 1,5 fois supérieurs dans le groupe B, en lien avec le plus grand nombre de sujets, d'un âge plus avancé et d'une prévalence supérieure du tabagisme. Les réductions estimées seraient supérieures si davantage de maladies, une tranche d'âge plus large et un suivi plus long étaient pris en compte. Les limites méthodologiques n'auraient aucun impact sur la conclusion selon laquelle l'introduction de ces produits en Allemagne en 1995 aurait sensiblement réduit le nombre de décès et d'années de vie perdues dans les deux groupes, avec un avantage pour le groupe B.

Conclusions: Bien que l'arrêt du tabagisme soit la solution optimale pour réduire la mortalité, une conversion à des produits à risque réduit apporte également un gain substantiel pour la santé. Une approche de santé publique encourageant les fumeurs des groupes socioéconomiques inférieurs à passer à des produits à risque réduit pourrait diminuer les inégalités sanitaires causées par le tabagisme, par rapport à la poursuite du tabagisme. [Contrib. Tob. Nicotine Res. 31 (2022) 52–67]

ABBREVIATIONS	
COPD	chronic obstructive pulmonary disease
DD	drop in deaths
ECig	e-cigarette
E-component	epidemiologic component
H	half-life
HnB	heat-not-burn
IHD	ischaemic heart disease
LC	lung cancer
P-component	prevalence component
RR	relative risk
RRP	reduced-risk product
SEG	socioeconomic group
TP	transition probability
YLS	years of life saved

INTRODUCTION

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 (here cigarettes, ECigs or HnBs), transitions between products, and mortality might vary by socioeconomic group (SEG), a possibility allowed for in the current paper.

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 recently (3). Smoking is believed to contribute to health-related inequalities between SEGs, for example as regards quality of life, morbidity, and mortality (4–7). Lower success rates in quitting smoking in lower SEGs contribute to these differences (8–11). Targeted smoking cessation interventions could help reduce social inequalities, while untargeted interventions are likely to have increased inequalities (12).

While smokers would best quit smoking, switching to RRPs is an alternative that may reduce their disease risk, and the one we investigate here. There are numerous examples of how switching to RRPs can work, including the use of snus in Sweden (13), ECigs in the UK (14), and HnBs in Japan (15) as well as the modelling shown in our companion paper on the use of ECigs and HnBs in Germany. Recent studies have also suggested that RRPs like ECigs can aid smoking cessation (14, 16, 17) and they have become the most popular cessation aid in Germany (18) and the UK (19). It has recently been proposed that the effect of ECigs on cessation might narrow the health inequalities from smoking (20).

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 RRPs (ECigs and HnBs) in Germany on two different SEGs. We investigate various assumptions about the rate of uptake and compare the estimates of DD and YLS with those derived assuming that all smokers in Germany quit immediately.

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

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

Such estimates are useful in themselves as they could inform policy decisions by enabling cost-benefit considerations for tobacco control and educational programs targeted at the most vulnerable SEGs to increase smoking cessation or, if needed, switching to less harmful products.

MATERIALS AND METHODS

Outline of the approach used

The method used for estimating the 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 using sets of product use transition probabilities (TP) that vary by SEG as well as by sex, age, and length of follow-up. For modelling we used the German Socioeconomic Panel data which provides prevalence data for 2002 and 2012 for current and former smoking by SEG. The data and method of socioeconomic status classification were described earlier by BENNEWITZ and KAUL (21). As before, individuals are followed up under the Null Scenario, where RRPs are never introduced, and various Alternative Scenarios, where one or more RRPs 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 YLS associated with RRP introduction is as in our companion paper. The estimation is based on the negative exponential model and requires estimates of the relative risk (RR) and quitting half-life (H) 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 individual 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 is based on a combination of net income per household and mean years of education, as described by FOREMAN *et al.* (22).

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 S1 expands on how the higher and lower SEGs A and B were defined and the implications that our definition might have on our results.

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 used in the companion paper (21, 23, 24), only the estimates for 1995 being required for the baseline population. See also Section 2 of Additional File S1.

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 US estimates (25). See also Section 3 of Additional File S1. 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 SEG 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 of B overall (for age 10–79 years) were older than those in A, in men by 3.85 years and women by 8.82 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.

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 S2 and are shown in Table 3. To test the validity of the TPs, prevalences predicted based on these TPs were compared with the estimates for Germany derived as described above for years up to 2015.

Estimation of histories of product use for the Alternative Scenarios

In the companion paper, we considered seven different Alternative Scenarios, numbered 1 to 7. Here, we only considered four of these (1, 3, 6, and 7), the original numbering being retained to facilitate comparison between the two papers. 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 RRPs (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.

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
Population [b]	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
Population [b]	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	38.10	38.74	41.52	51.54

[a] Sources used: see text. Data on the distribution by SEG were for 2002 but taken to apply to 1995. [b] Populations are given in hundreds. 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.

In Alternative Scenarios 6 and 7 the market shares of HnBs and ECigs in 2005 are 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 RRPs, 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 both Alternative Scenarios to ensure comparability with the Null Scenario TPs, the only difference between the scenarios being in the assumed rate of switching between products.

For the Alternative Scenarios where RRPs are introduced 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, compared to 1 for exclusive cigarette use.

The full set of Alternative Scenario TPs is presented in Additional File S3.

Factors affecting TPs

As previously, the option to allow TPs to depend on previous product history was not used.

Transitions between SEGs

Table 4 presents the annual TPs used to allow transition between SEGs. These were derived as described in Additional File S4.

Estimating RRs from 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

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	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.

deaths from 1995 to 2015 are presented in our companion paper. Using these data, the method of estimating the numbers of deaths and increase in death rates associated with smoking is as described earlier (25).

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 described there. SEG-specific estimates were obtained by multiplying these values by the proportions in the SEGs. Additional File S5 presents the mortality data by SEG.

An additional analysis

Differences in the estimated DD and YLS between SEGs A and B may arise both because of differences between SEGs in the prevalence of smoking habits and in age distribution. To gain insight into which of these was more 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 S6.

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 those 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. Distributions for other age groups are shown in Additional File S6.

Figure 2 presents 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, as expected, identical to those in the Null Scenario shown in Figure 1. The main difference between Figures 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.

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

		SEG A						SEG B					
Period (years)	Age (years)	Initiation (P_{NC})		Quitting (P_{CF})		Re-initiation (P_{FC})		Initiation (P_{NC})		Quitting (P_{CF})		Re-initiation (P_{FC})	
		Men	Women	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
1–5	10–14	4,296	3,462	2,446	1,454	1,166	695	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	13,030	9,824	4,406	5,752	2,088	2,714
	20–24	2,560	2,712	4,631	2,808	2,193	1,337	5,277	2,470	964	3,630	461	1,724
	25–29	173	1,301	3,411	2,390	1,621	1,139	2,432	1,663	1,061	2,619	508	1,247
	30–34	516	638	3,695	2,532	1,755	1,207	778	723	1,251	1,770	599	845
	35–39	0	0	4,007	2,891	1,901	1,376	0	0	1,474	981	705	470
	40–44	0	0	3,569	2,089	1,696	997	0	0	2,506	1,935	595	319
	45–49	0	0	4,041	2,396	1,434	855	0	0	3,506	1,903	414	181
	50–54	0	0	5,040	3,463	1,184	504	0	0	3,733	1,789	220	128
	55–59	0	0	4,487	6,368	527	404	0	0	2,756	3,032	163	108
	60–64	0	0	2,153	6,226	256	305	0	0	2,859	7,788	84	70
	65–69	0	0	2,252	3,685	134	195	0	0	4,057	10,198	60	46
	70–74	0	0	2,673	3,020	79	125	0	0	5,292	14,584	39	32
	75–79	0	0	2,673	3,020	79	125	0	0	5,292	14,584	39	32
6–10	10–14	3,654	2,986	2,063	2,210	985	1,054	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	9,496	10,212	3,177	9,730	1,511	4,537
	20–24	978	1,993	4,476	3,470	2,120	1,649	3,359	2,024	1,323	3,327	633	1,582
	25–29	320	967	4,047	3,044	1,920	1,448	1,179	1,197	1,238	2,250	592	1,073
	30–34	461	477	4,158	3,100	1,972	1,475	760	380	1,640	1,462	784	699
	35–39	0	0	4,044	3,056	1,919	1,454	0	0	1,954	937	933	449
	40–44	0	0	3,146	2,798	1,496	1,201	0	0	2,219	1,468	791	354
	45–49	0	0	3,751	3,440	1,333	1,059	0	0	2,907	1,588	684	189
	50–54	0	0	4,358	4,121	1,027	786	0	0	3,276	1,900	430	113
	55–59	0	0	3,865	5,097	455	495	0	0	2,947	2,848	316	84
	60–64	0	0	2,627	4,689	311	462	0	0	2,853	4,239	153	62
	65–69	0	0	2,680	3,966	159	364	0	0	3,824	4,840	101	35
	70–74	0	0	3,144	4,767	93	205	0	0	4,687	5,286	61	22
	75–79	0	0	3,144	4,767	93	205	0	0	4,687	5,286	61	22
11+	10–14	2,883	2,072	1,840	3,593	879	1,706	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	6,837	11,864	1,340	17,133	640	7,807
	20–24	374	1,186	5,489	3,933	2,593	1,865	1,323	1,495	1,532	2,845	732	1,355
	25–29	463	573	5,296	3,823	2,503	1,815	1,852	678	2,093	1,715	998	819
	30–34	409	283	5,029	3,931	2,379	1,866	1,718	190	2,458	1,141	1,171	546
	35–39	0	0	4,385	3,091	2,078	1,470	0	0	2,727	874	1,299	419
	40–44	0	0	2,750	3,681	1,309	1,146	0	0	1,856	1,166	886	301
	45–49	0	0	3,376	5,215	1,085	694	0	0	2,293	1,958	819	233
	50–54	0	0	3,432	4,989	703	499	0	0	3,219	2,218	646	132
	55–59	0	0	3,139	4,394	318	436	0	0	3,077	2,882	305	85
	60–64	0	0	2,893	3,412	278	340	0	0	3,259	2,316	160	69
	65–69	0	0	3,015	4,064	142	203	0	0	3,821	2,463	94	36
	70–74	0	0	3,571	7,872	83	148	0	0	4,223	2,245	52	33
	75–79	0	0	3,571	7,872	79	125	0	0	4,223	2,245	39	32

The first period (1–5) relates to the 5 years starting in 1995, the second period (6–10) to the 5 years starting in 2000, and the third period (11+) 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 RRPs 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.
Note that yearly TPs can be derived from monthly TPs, given the assumption that only one transition may occur in one year, using the formula $P\ (1\ \text{year}) = 1 - (1 - P\ (1\ \text{month}))^{12}$.

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 S6. For all Alternative Scenarios, Additional File S7 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.

Table 4. Annual probabilities of transition between 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.

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, the variation between 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 each scenario. They 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.

The DDs in the Conversion Scenario are also shown by sex, disease, and SEG over the whole follow-up period in Figure 3. The pattern of results in each SEG is similar to that described in our companion paper, the largest DDs in both sexes being in scenarios 1 and 3, with smaller DDs in scenarios 6 and 7, where the switch to RRPs 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.

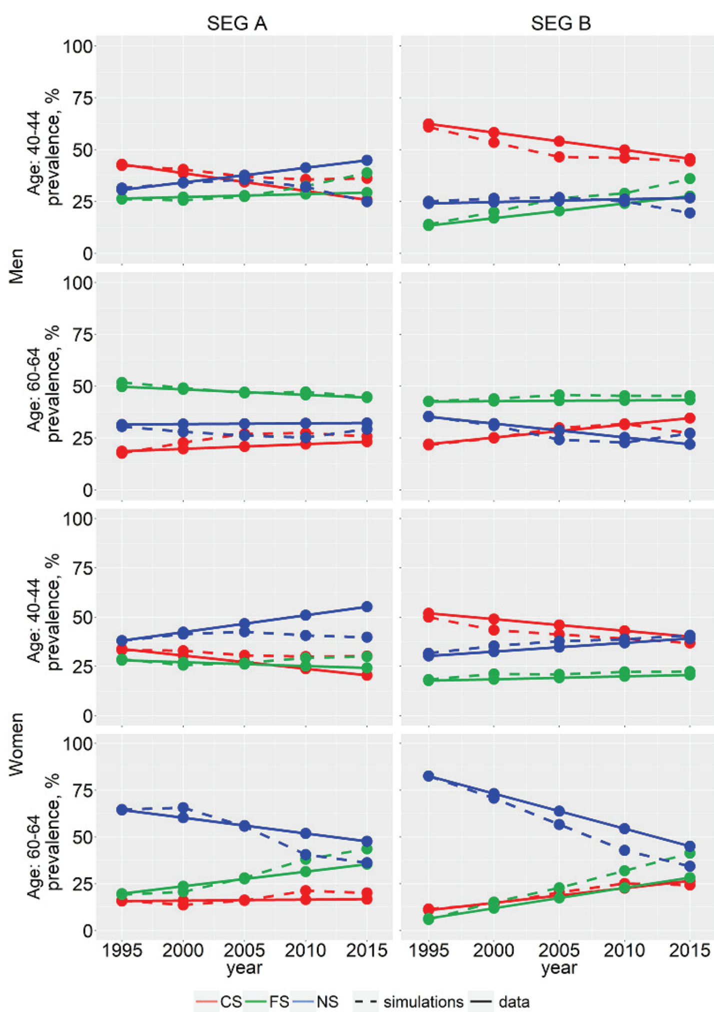

Figure 1. Comparison of Null Scenario and derived estimates of current smoking prevalence.

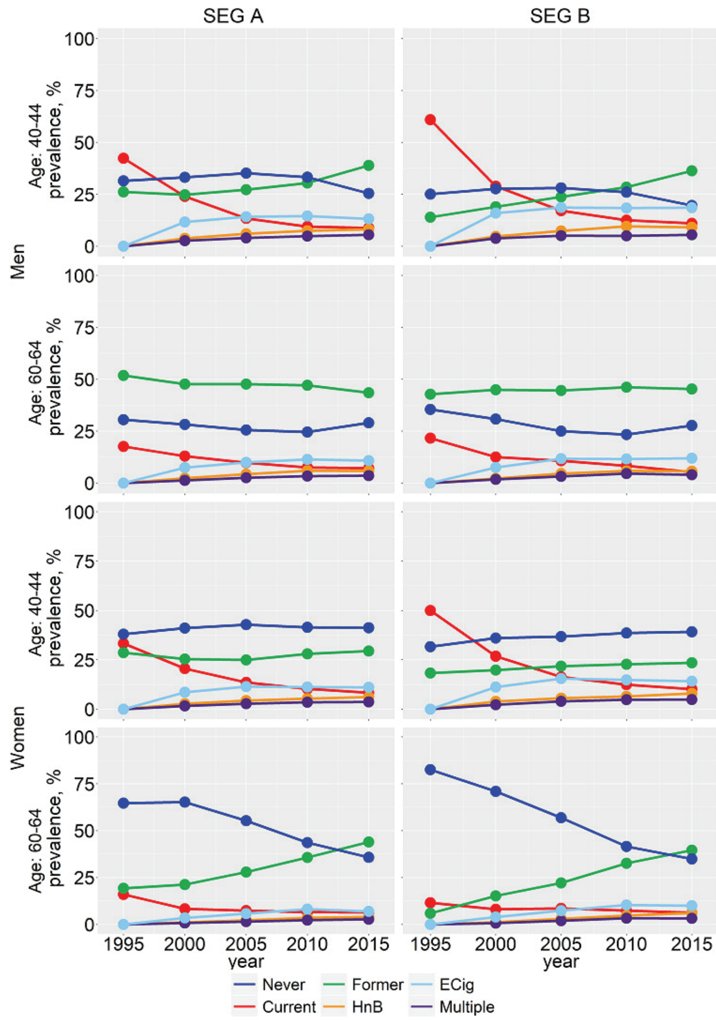

Figure 2. Nicotine usage in the Conversion Scenario.

In all the scenarios, DDs are 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, 72,725, 60,081, 24,010, and 25,648 for SEG A and 147,684, 122,343, 50,385, and 52,652 for SEG B, the DD for B always being 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. As the proportions by SEG vary substantially by age (see Table 1), the ratio of DDs for B to A also does. 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, all four diseases, and each scenario (see Additional File 6).

The total DD in SEGs A and B combined can be seen as an SEG-adjusted total, which can be compared with the unadjusted estimates in Table 4 in our companion paper. They are quite similar. Thus, the unadjusted DDs of 56,263 among men and 18,132 among women for the 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 Figure 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, as individuals in B are more likely to be older 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.

Table 5. Drop in deaths by SEG over the follow-up period in Germany in the Alternative Scenarios.

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 RRPs (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 RRPs (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	13.13	47.22	47.10	16.69	24.85
	3	Complete switch to RRPs (50% HnBs, 50% ECigs)	38,259	72,180	13,623	11,956	136,018	10.67	39.05	40.09	14.24	20.56
	6	Conversion Scenario	14,963	30,014	6,056	5,230	56,263	4.17	16.24	17.82	6.23	8.51
	7	Full Conversion Scenario	15,746	31,574	6,348	5,467	59,136	4.39	17.08	18.68	6.51	8.94
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 RRPs (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	15,98	13,209	5,264	4,916	39,369	20.66	45.87	51.20	23.60	28.68
	3	Complete switch to RRPs (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	21.46	48.42	51.27	23.73	29.88
	3	Complete switch to RRPs (50% HnBs, 50% ECigs)	18,324	15,923	6,677	5,481	46,406	17.34	40.47	43.58	20.19	24.75
	6	Conversion Scenario	6,732	6,292	2,798	2,310	18,132	6.37	15.99	18.26	8.51	9.67
	7	Full Conversion Scenario	7,143	6,640	2,962	2,419	19,164	6.76	16.88	19.33	8.91	10.22

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 total number of smoking attributable deaths in the null scenario for LC, IHD, Stroke, COPD and all four diseases were, respectively, 105,798 57,119 10,838 23,076 and 196,830 for men in group A, 252,847 127,700 23,143 60,908 and 464,597 for men in group B, 28,333 10,547 5,041 6,318 and 50,239 for women in group A and 77,367 28,795 10,281 20,829 and 137,272 for women in group B.

Table 6. YLS (thousands) by age 75 by SEG over follow-up in Germany in the Alternative Scenarios.

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 RRPs (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 RRPs (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.

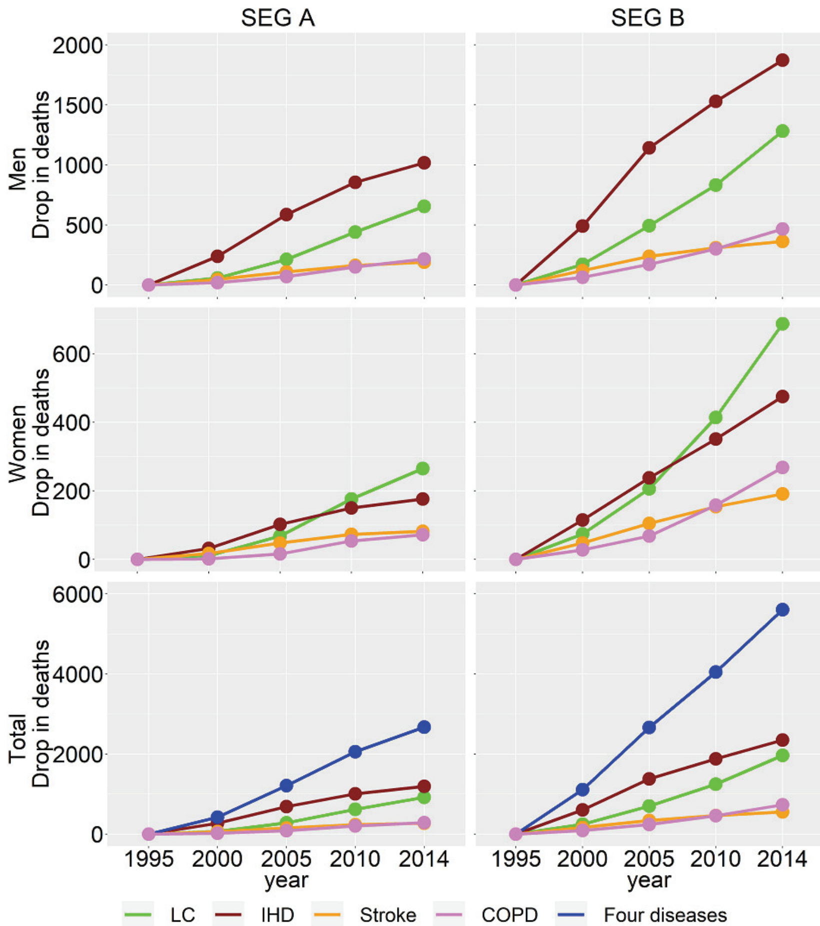

Figure 3. DDs in the Conversion Scenario over the whole follow-up period.

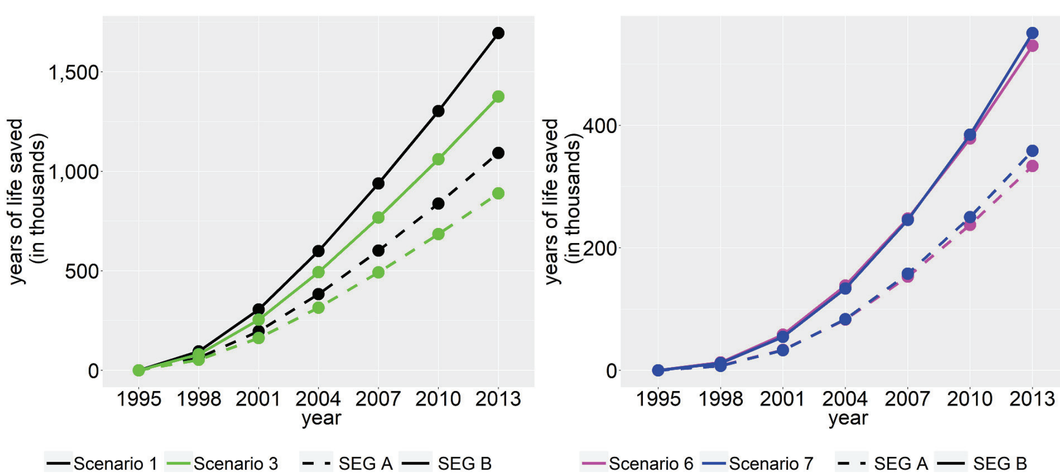

Figure 4. YLS by Scenario and SEG over the whole follow-up period.

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.

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 S6.

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 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, the smoking-related diseases, we consider here, originate from smoking, not from age differences, which is why public health measures have focused on lowering smoking prevalence to curb the health consequences of smoking cigarettes.

DISCUSSION

This is the first study to estimate the population health impact of introducing RRPs 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 SEG, we estimated that, in scenarios 1 (Complete cessation), 3 (Complete switch to RRPs–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 similar (220,409, 182,424, 74,395, and 78,300). Our results suggest that taking SEG into account little affected the overall estimated DDs, and that substantial DDs were seen in both SEG groups, A and B, with the drops about twice as high in B as in A.

The estimates of population health impact in both SEGs are likely to be pessimistic for the four main reasons discussed in our companion paper: deaths were only counted for four diseases; deaths above age 79 years were not considered; only a 20-year follow-up period was considered; and no account was taken of the possibility that cigarette smokers taking up HnBs and ECigs might be more likely to quit cigarettes completely than those who do not take up these products. We also note that the RRs we have used for current and former smoking (based on published meta-analyses) are lower than those used by others (based on specific studies) when estimating deaths attributable to smoking in Germany (26). 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 we have assumed, or if cigarette smokers taking up HnBs and ECigs, compared to those who do not, are less likely to quit smoking or tend to increase their cigarette consumption. There is little evidence, however, that the latter is the case.

While scientific consensus accumulates that RRPs like ECigs and HnBs represent less risk than cigarettes (27, 28), there has been debate on whether smoking-related health inequalities between SEGs could be reduced by smokers switching to RRPs (29). Some studies found more advantaged smokers to be more likely to use ECigs in the UK (30) or HnBs in Germany (31), while others recently observed that ECigs might help disadvantaged smokers to quit (20). ECigs might have contributed to some of the highest UK smoking cessation rates so far, with parity across SEGs (32). 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 RRPs as substitutes for cigarettes, ECigs being the most popular quitting aids in the UK (19) and Germany (18, 33). It is notable that conventional pharmacotherapies for smoking cessation are more commonly used in Germany by smokers with higher incomes (18, 33), 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 (33). On the other hand, use of ECigs, the most popular quitting aid, was not associated with income or education, underlining that RRPs could be a promising addition to public health strategies aimed at providing equal chances for smokers from different SEGs to exit out of cigarettes (33).

Data from several countries show that lower social grades and level of education are significantly linked to inaccurate harm perception of ECigs (27, 34). 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 (35). Given ECigs are likelier to be used for smoking cessation if perceived as less harmful than cigarettes (36), misperceptions might well be discouraging many smokers from trying RRPs. Improving perception seems particularly important for disadvantaged populations of smokers, such as those in lower SEGs, who could benefit more from RRPs as a harm reduction tool.

Uptake of RRPs by smokers is also affected by factors such as taxation (37), affordability (38), moral concerns around addiction (39), and consumer choice regarding ECig flavors (40). 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 (10). Clear communication of relative risks by targeted public health educational campaigns could help realize the potential of RRPs for harm reduction among lower SEGs.

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 on future death rates. Our methodology also allows the population health impact of RRP introduction to be estimated under various assumptions and by SEG.

There are, however, some potential limitations 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 uptake rates of HnBs and ECigs have been discussed in our companion paper and are not considered further here. Also failure to account for 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 the estimation of population health impact by SEG merit consideration. One is that the age- and sex-specific prevalence data for current and former smoking in Germany by SEG was only available for two years (2002 and 2012), so that annual data had to be estimated by a combination of interpolation/extrapolation and smoothing (see Additional File S1). More detailed source data might have led to some revision of our estimates, but it seems unlikely this would have made much difference, given that 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 (see Additional File S2) are calculated using the distribution of smoking habits in the same birth cohort five 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 seems 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 (see Additional File S4) 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 as re-running the analyses for Alternative Scenario 6 by disallowing the possibility of transfer little affected the overall estimates and only slightly reduced the estimated DDs shown in Table 5, changing 19,007 to 18,738 [A men], 37,256 to 37,193 [B men], 5,003 to 4,962 [A women], and 13,129 to 12,999 [B women]. (Detailed results not shown.)

A potential criticism relates to how we defined the SEGs. As noted earlier, we used an established method (22) based on a combination of net annual income and mean years of education. As our population health model is not restricted to a single method for deriving SEGs and accommodates alternative approaches for doing so, it provides an excellent basis for future research on this topic.

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.

CONCLUSIONS

Our population health impact model showed that introducing RRPs (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 (18), tobacco harm reduction by fully switching to RRPs represents a public health opportunity currently unexploited 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 suggest that inclusive access to RRPs, 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 encouraging low SEG smokers who would otherwise continue to smoke to switch to RRPs, and complemented by risk-based regulation, could synergize with tobacco control measures targeted at lower SEGs to further reduce such inequalities.

DECLARATIONS

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable

CONSENT FOR PUBLICATION

Not applicable

AVAILABILITY OF DATA AND MATERIAL

The data on population size, mortality, smoking prevalence, and distribution by SEG used in this study are publicly available from the sources described in the paper. The sources of the data used for the RR and H values are also shown.

COMPETING INTERESTS

JF and PL are independent consultants in statistics and advisers in epidemiology to several tobacco companies. AK and EB acted as consultants for Philip Morris International. SD is a former employee and AKN and RR are current employees of Philip Morris International.

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All the work described in the paper was funded by Philip Morris International. The authors are wholly responsible for designing the study, conducting the analyses, interpreting the results, and writing the manuscript.

AUTHORS' CONTRIBUTIONS

The work described here was conceived by RR, SD, AKN, and PNL. Some of the data required were 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 according to comments by RR, SD, EB, and JSF. All authors read and approved the final manuscript.

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SUPPLEMENTARY INFORMATION

Additional File S1.pdf
Title: Derivation of the SEGs and estimates of cigarette smoking habits by SEG for Germany.
Description: This document describes the methods used to classify individuals in Germany by SEG and to derive estimates of their cigarette smoking habits by SEG.

Additional File S2.pdf
Title: Derivation of TPs by SEG for the Null Scenario.
Description: This document describes the derivation of the TPs by SEG for the Null Scenario for Germany.

Additional File S3.pdf
Title: TPs by SEG for each Alternative Scenario.
Description: This document presents the TPs by SEG for each Alternative Scenario for Germany.

Additional File S4.pdf
Title: Derivation of rates of transfer between the SEG groups.
Description: This document describes the derivation of the rates of transfer between the SEG groups for Germany.

Additional File S5.pdf
Title: Data on number of deaths by sex, age, year, and SEG.
Description: This document presents the data on the numbers of deaths per year from LC, COPD, IHD stroke used for Germany by SEG. The data are shown by sex, year (1995, 1996...2012), age group (30–34, 35–39…75–79 years), and SEG (A and B).

Additional File S6.pdf
Title: Full output for each Scenario.
Description: This document provides the full computer output relating to the estimated DDs and YLS by SEG, preceded by a description of the contents of the output.

Additional File S7.pdf
Title: Product use distributions by SEG.
Description: This document provides current product use distributions by SEG in 2005 for all scenarios and the overall prevalence of current product users by SEG in 2010.