Smoking is harmful to health\textsuperscript{1,2} and the health benefits of smoking cessation have been documented.\textsuperscript{3} We have found that smoking imposes costs to society, even when taking non-smokers longer life span into consideration.\textsuperscript{4} However, from a policy point of view it is of interest what the savings of smoking cessation are. Few studies have estimated the economic impact of smoking cessation in a lifetime perspective, and findings are unclear. Oster \textit{et al.}\textsuperscript{5} found the economic benefits of quitting, estimated from direct and productivity lifetime costs based on three smoking-related diseases, to be sizeable for all groups of smokers; however, they did not take life expectancy into account. Barendregt \textit{et al.}\textsuperscript{6} included life expectancy and reported 15\% higher direct lifetime health care costs in non-smokers (never smokers and ex-smokers) than in smokers, and characterize anti-smoking interventions as unattractive in a narrow economic sense. In Barendregt \textit{et al.}'s results, only 20\% of lifetime health care costs are related to smoking. This is based on the assumption that only costs for heart disease, chronic obstructive pulmonary disease and cancers are related to smoking. In our view, this may be an underestimation.

We estimated the economic savings of complete smoking cessation to the Danish society in a lifetime perspective comparing continuing smokers' and ex-smokers' total costs, and decomposed the costs in direct (health care) lifetime costs and productivity lifetime costs, i.e. costs due to reduced labour supply. We included a broader set of smoking-related diseases than previous studies.\textsuperscript{5,6} Extensive sensitivity analyses were performed to ensure that results were robust to the assumptions made.

**Methods**

The economic effect of smoking cessation was examined in a lifetime perspective, comparing the health costs of continuing smokers and ex-smokers by quantity of daily tobacco consumption (light smokers, 1–14 g; moderate smokers, 15–24 g; and heavy smokers,>24 g), age of quitting smoking, gender and disease group. The health costs and the savings of smoking cessation to the society included all costs related to smoking from age 35 years through age 89 years under the assumption that outside this age interval, the effects of smoking on the health costs are negligible. It was assumed that once smokers quit smoking, they are ex-smokers for life. We defined total health costs as the sum of direct costs and productivity costs. Costs of the Danish population in 1999 were studied within four disease groups: cancer (ICD-10: C00-C99), vascular disease (ICD-10: 100-199), respiratory disease (ICD-10: 100-199) and 'all other diseases'.

The estimation of the total, direct and productivity lifetime health costs for continuing smokers and ex-smokers was based on data from a previous study that estimated the total lifetime costs in 1999 for ever-smokers and never-smokers. Annual smoking-attributable direct and productivity costs (population 5 million; overall smoking prevalence among adults 35\%) amounted to 1310 and 1880 million \euro, respectively (exchange rate 1999: 743.57 DDK per 100 \euro).\textsuperscript{4} The direct costs were estimated by the economic resources used in the health-care sector; including costs from discharges, outpatients (including casualty ward consultations), drugs and consultations with general practitioners and physiotherapists. The productivity costs included costs from morbidity (early retirement and absentee days) and mortality. The productivity costs were estimated by the human capital method, the most commonly used method, as the value of loss of production caused by short-term, long-term or permanent cessation of work activity caused by smoking related diseases and premature death.
Estimation of the total lifetime health cost savings of smoking cessation combines the cost of illness and life expectancy. Population attributable risk percentages (PAR) were used as indicators for parts of output as well as parts of smoking-attributable costs. Using Danish quantity-, age- and gender-specific smoking proportions for current smokers and Danish quantity-, gender- and disease-specific estimates of relative mortality risks (RR), the quantity- (q), age- (a), gender- (g) and disease-specific (d) PARs (PARqagd) were estimated with an algorithm used by King et al. Furthermore, the quantity-, age- and gender-specific PARs (PARqagd) were estimated based on RR estimates for all causes. Estimating the PARqagd and PARqag in ex-smokers it was assumed that 15 years after smoking cessation, the mortality risks among ex-smoking men and women reversed linearly to that of never-smokers, irrespective the quantity of daily tobacco consumption.

In the international literature, it has been reported that the RR increases with amount of tobacco smoked. This pattern does apply to the Danish RR estimates, except for vascular diseases and all other diseases in heavily smoking men. From the Danish study, it appears that heavily smoking women's RR estimates in vascular diseases and all other diseases exceed moderately smoking women's by a factor 1.1 and 1.2, respectively. Owing to some uncertainty on the Danish RR estimates, the RR estimates for vascular diseases and all other diseases in heavily smoking men were increased proportional to moderately smoking men.

Continuing smokers' and ex-smokers' annual quantity-, age-, gender- and disease group-specific smoking-attributable direct (ADCqagd) and productivity (APCqagd) costs per person-year were estimated by multiplying the annual direct and productivity costs by age, gender and disease group by the PARqagd, and afterwards by calibrating and multiplying by the fraction of daily tobacco consumption. APCqagd/PARqagd and dividing by the number of persons in the category in question.

Owing to non-additivity and sample variation of the PAR estimates, the sum of annual disease-specific smoking-attributable costs (ACqagd) exceeded annual smoking-attributable costs (ACqag), estimated from the PARqag estimates. Therefore, ACqagd were calibrated by excess reduction proportional to their share of the sum of ACqagd.

As implicit in the estimation of PAR, the remaining annual direct and productivity costs were assumed to be independent of the smoking status, and they were assigned according to age, gender and disease group. The annual total costs per person-year were estimated by quantity of daily tobacco consumption, age, gender and disease group by adding the direct and productivity smoking-attributable costs to the annual direct and productivity remaining costs.

Based on the standard life table from Statistics Denmark (1998–1999), the survival probabilities were estimated by smoking status and gender, conditionally on being alive at given ages (35, 36, . . . , 89 years). By multiplying annual costs per person-year by the survival probabilities and discounting by 5% per year, total, direct and productivity lifetime health costs were obtained for continuing smokers by quantity of daily tobacco consumption and for ex-smokers by daily tobacco consumption and given age at quitting (u) (35, 40, . . . , 65 years). Total lifetime health cost estimation assumes that a 45-year-old's costs per person-year are an appropriate estimate of a 35-year-old's costs per person-year in 10 years (stationarity assumption). The economic savings of smoking cessation to society were estimated as the difference in the total, direct and productivity lifetime health costs between 35-year-old continuing smokers and 35-year-old ex-smokers at given age at quitting. The relative total lifetime health cost savings of smoking cessation to society (TLCqagd) in ex-smokers who quit smoking in given ages (u) by daily quantity of tobacco consumption (q), gender (g), disease group (d) and costs (c) (running from age 35 years to 89 years for the direct lifetime costs and from age 35 years to 69 years for the productivity lifetime costs) were estimated as:

$$TLC_{qagdcu} = (TLC_{qagdc} - TLC_{qagdcu})/TLC_{qagdc}$$

where TLC_{qagdcu} is the total lifetime health costs for continuing smokers by daily quantity of tobacco consumption, gender, disease group, cost and given age at quitting.

### Sensitivity analyses

The sensitivity of the results of the analysis was examined by repeating the analysis: (i) with different time-span for ex-smokers mortality risk to reach never-smokers' level, lower (RRu) and upper bounds (RRu) being 15 years (+ (0.5 * 15 years) and 15 years – (0.5 * 15 years); and (ii) with different discount rates (no discounting and 8% per year).

### Results

Figure 1 shows the total lifetime health cost savings of smoking cessation to society as 35-year-old continuing smokers' excess total lifetime health costs by quantity of daily tobacco consumption, gender and cost category compared with 35-year-old ex-smokers at given age at quitting. It is shown that the difference varies with age at quitting, quantity of daily tobacco consumption and gender. The total, direct and productivity lifetime health cost savings of smoking cessation in 35-year-old moderate smokers, who quit smoking at the age of 35 years, are 24 800 €, 7600 € and 17 200 € in men, and 34 100 €, 12 200 € and 21 800 € in women, respectively. Comparing 35-year-old ex-smoking men who quit smoking at the age of 35 years with 35-year-old continuing smokers, the direct lifetime health cost savings of smoking cessation to society are 30–42%. The corresponding results are 34–43% in ex-smoking women. However, the direct lifetime cost savings of smoking cessation to society is reduced to <12% in 35-year-old ex-smokers who quit smoking later than age 55 years. The productivity lifetime costs savings are minimal in ex-smokers who quit smoking after age 50 years.

Table 1 presents the total cost savings of smoking cessation to society in ex-smokers who quits smoking at the age of 35 years by disease group and cost. All disease groups are associated with lower costs in ex-smokers than in continuing smokers. This relation is particularly strong for the diseases with the highest excess risk: cancers and respiratory diseases. The direct lifetime health cost savings associated with cancers and respiratory diseases are as much as 33–57% and 51–52% in men, and as much as 35–53% and 63–68% in women, respectively. However, the direct lifetime health costs savings of cancers and respiratory diseases only amount to 20–23% of the direct lifetime health cost savings in men, and 24–28% in women, respectively. The direct lifetime health cost savings in all other diseases’ are 29–41% and 29–38% in men and women, but amount to 58–65% and 58–61% of the direct lifetime health cost savings in men and women, respectively. The relative productive lifetime costs savings in men and women are very similar to the direct lifetime cost savings in the same disease groups. Table 1 also shows that the overall results were the same within a broad range of years decreasing ex-smokers’ mortality risk to the never-smoker level.

Table 2 shows that ex-smokers’ percentages for direct and productivity lifetime health costs savings are robust to different discounting rates in both men and women. Without discounting, 35-year-old ex-smokers’ direct lifetime health cost savings are 28%, 32% and 48% in light, moderate and heavily smoking men, respectively. The corresponding direct lifetime health costs savings discounted with 8% per year are 29%, 33% and 38%, respectively. Very similar results are shown in women.
Discussion

We found that total lifetime health cost savings of smoking cessation are substantial. The direct and productivity lifetime health cost savings were highest at the younger ages, taking the difference in life expectancy and the reduced smoking RR after smoking cessation into account. Although the savings vary with age at quitting, gender and quantity of daily tobacco consumption, all ex-smoking men and women who quit smoking at the age of 35–55 years generate sizeable total lifetime cost savings. At older ages, the total lifetime health cost savings have little economic consequences to society.

The validity of the estimated total lifetime health costs depends on unbiased estimates of epidemiological and economic parameters. The distribution of costs in this study was based on RRs derived from mortality rates and applied to both mortality- and morbidity-related data. Several studies have indicated that smoking-related risks of absentee days, hospital discharges, early retirement, visits to general practitioner and use of prescription medicines are of similar size to that of all-cause mortality. It has been shown that smokers have an increased risk of developing diseases such as pneumonia, gastric and duodenal ulcers, osteoporosis, hip fractures, and type 2 diabetes. We therefore estimated the PARs for ‘all other diseases’ from the relative mortality risks. In addition, the present study was examined by repeating the analysis with different RRs, the lower and upper bounds of each RR being and . Although lower RRs reduced the economic cost savings of smoking cessation (data not shown), there were still sizeable total lifetime health cost savings in ex-smokers who quit smoking at the age of 35–50 years.

By calibration of the ACagd, the sum of ACqagd is reduced by 2–8% in light and moderate smokers and by 15–18% in heavily smoking women compared with ACag, whereas the sum of ACqagd in heavily smoking men is increased by 5–12%. This reduces the economic cost savings of smoking cessation except for heavily smoking men, but does not effect the relative lifetime health cost savings.

Figure 1 The total lifetime health cost savings of smoking cessation to society in 35-year-old ex-smokers at given age at quitting, by gender, cost and quantity of daily tobacco consumption. Direct and productivity lifetime health costs are truncated at the age of 89 and 69 years, respectively. Five percent discount rate; Denmark 1999; € (exchange rate 1999: 743.57 DDK per 100 €).
The direct lifetime health cost savings reported are very similar to both the annual hospital costs (discharges and outpatient costs) and all the direct costs (consultations with general practitioners and physiotherapists, drugs and hospital costs), in men and women aged 35–89 years in 1999. Cancers and respiratory diseases in total amounted to 20% of the total hospital costs in both genders and the disease group ‘all other diseases’ amounted to 53% and 61%, respectively. The corresponding distribution for the annual direct costs for cancers and respiratory diseases was 27% and 20%, and for ‘all other diseases’ was 56% and 66%, respectively.

Several studies have documented that smoking cessation reduces the risk of diseases and the risk of premature death compared with continuing smoking. One American study showed that 16 years after quitting, the mortality risk among ex-smoking men of fewer than 21 cigarettes/day reached that of never-smokers, but remained elevated among ex-smokers of 21 cigarettes or more. Among ex-smoking women in both smoking categories, the mortality risk was comparable to that of never-smokers after 16 years of abstinence. These results are broadly in agreement with other results. Time since quitting smoking is known to affect RRs differently for different disease categories; for example, risk of cardiovascular disease is believed to decrease relatively rapidly, whereas risk of lung cancer and chronic obstructive pulmonary disease declines much more slowly. Since the precise time course of risk reduction is subject to some uncertainty, we assumed in the present study that 15 years after smoking cessation the overall and cause-specific mortality risk in ex-smokers reversed linearly to that of never-smokers, irrespective the quantity of tobacco consumption. Furthermore, we have a rather broad range of years for ex-smokers’ disease risk to reach level of never-smokers.

<table>
<thead>
<tr>
<th>Gender and cost</th>
<th>Disease group</th>
<th>Light</th>
<th>Relative cost savings</th>
<th>Moderate</th>
<th>Relative cost savings</th>
<th>Heavy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cost savings 1000 €</td>
<td>Relative cost savings [% (sensitivity range)]</td>
<td>Cost savings 1000 €</td>
<td>Relative cost savings [% (sensitivity range)]</td>
<td>Cost savings 1000 €</td>
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<tr>
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<td>Direct costs</td>
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<td>30 26–35</td>
<td>7.6</td>
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<td>Cancer</td>
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<td>33 30–36</td>
<td>0.9</td>
<td>45 40–48</td>
<td>1.2</td>
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<tr>
<td></td>
<td>Respiratory</td>
<td>0.8</td>
<td>52 47–58</td>
<td>0.8</td>
<td>51 45–58</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Other diseases</td>
<td>3.4</td>
<td>29 24–35</td>
<td>4.7</td>
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<td>6.1</td>
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<tr>
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<td>9.0</td>
<td>34 29–40</td>
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<td>15.6</td>
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<tr>
<td></td>
<td>Cancer</td>
<td>0.9</td>
<td>35 30–39</td>
<td>1.0</td>
<td>38 33–42</td>
<td>2.1</td>
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<tr>
<td></td>
<td>Vascular</td>
<td>1.5</td>
<td>41 37–45</td>
<td>1.8</td>
<td>45 40–49</td>
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<td>1.4</td>
<td>38 34–73</td>
<td>2.0</td>
<td>38 34–73</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Other diseases</td>
<td>5.2</td>
<td>29 24–36</td>
<td>7.4</td>
<td>35 30–42</td>
<td>9.4</td>
</tr>
<tr>
<td>Women</td>
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<td>29 21–39</td>
<td>21.8</td>
<td>32 23–44</td>
<td>31.9</td>
</tr>
<tr>
<td></td>
<td>Cancer</td>
<td>2.3</td>
<td>33 24–42</td>
<td>2.7</td>
<td>35 26–45</td>
<td>5.8</td>
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<tr>
<td></td>
<td>Vascular</td>
<td>1.7</td>
<td>36 24–47</td>
<td>2.1</td>
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<td>2.4</td>
</tr>
<tr>
<td></td>
<td>Respiratory</td>
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<td>35 24–72</td>
<td>1.2</td>
<td>38 27–52</td>
<td>1.6</td>
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<td></td>
<td>Other diseases</td>
<td>11.5</td>
<td>26 19–36</td>
<td>15.8</td>
<td>30 21–42</td>
<td>22.1</td>
</tr>
</tbody>
</table>

a: Estimated as [(current smokers lifetime health costs – former smokers lifetime health costs)/current smokers lifetime health costs]*100%)
b: Quitting smoking at the age of 35 years
c: Light, 1–14 g daily tobacco consumption; moderate, 15–24 g daily tobacco consumption; heavy, ≥25 g daily tobacco consumption
d: Exchange rate (1999): 743.57 DKK per 100 ¥
e: The sensitivity range calculated with different years lowering the excess risk of death caused by smoking; lower (RR_l) and upper (RR_u) bounds are 15 years (0.5*15 years) and 15 years – (0.5*15 years), respectively
f: Estimated with the human capital method, truncated at 69 years
The present analysis may be limited by uncertainty of the smoking proportions, which were based on an omnibus survey. Self-report is generally accepted as a valid measure of smoking. However, in the omnibus surveys from 1999 and 1996, there were no heavy smokers among men aged 70 years and over, for which reason it has been impossible to estimate the economic savings for this group.

Longevity and discounting of future costs affect lifetime costs. However, by discounting we made costs that occur at different times better comparable; otherwise a given amount of money spent today would be worth more than the same nominal amount spent 15 years from now, even without inflation. No discounting increased the economic lifetime cost savings of smoking cessation and the relative direct and productivity lifetime health cost savings. Although higher discount rate (8% per year) considerably reduced the economic cost savings, lifetime health cost savings.* 5% 8% No discounting 5% 8% No discounting

<table>
<thead>
<tr>
<th>Gender and quantity of daily tobacco consumption</th>
<th>Relative lifetime health cost savings (sensitivity range)$^d$</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct lifetime cost savings</td>
<td>Productivity lifetime cost savings$^e$</td>
</tr>
<tr>
<td></td>
<td>5% 8% No discounting</td>
<td>5% 8% No discounting</td>
</tr>
<tr>
<td>Men</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td>30 29 28</td>
<td>25 23 30</td>
</tr>
<tr>
<td>Moderate</td>
<td>35 33 32</td>
<td>30 27 35</td>
</tr>
<tr>
<td>Heavy</td>
<td>42 38 48</td>
<td>35 31 41</td>
</tr>
<tr>
<td>Women</td>
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<tr>
<td>Light</td>
<td>34 31 34</td>
<td>29 26 34</td>
</tr>
<tr>
<td>Moderate</td>
<td>39 36 40</td>
<td>32 29 38</td>
</tr>
<tr>
<td>Heavy</td>
<td>43 39 43</td>
<td>38 34 45</td>
</tr>
</tbody>
</table>

a: Estimated as [(current smokers lifetime health costs – ex-smokers lifetime health costs)/current smokers lifetime health costs] × 100%
b: Quitting smoking at the age of 35 years
c: Light, 1–14 g tobacco per day; moderate, 15–24 g per day; and heavy, 24 g per day
d: The sensitivity range calculated with 8% per year and no discounting
e: Estimated with the human capital method, truncated at 69 years

The potential lifetime health cost savings of smoking cessation to society are substantial, in terms of both excess health-care utilization and reduced labour supply, even when the reduced life span of smokers is taken into account. The potential direct and productivity lifetime health cost savings of smoking cessation to society are highest at the younger ages.

**Conclusions**

**Acknowledgements**

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**Key points**

- What are the economic savings of smoking cessation to society estimated in a lifetime perspective?
- Direct lifetime health-care cost savings in a moderate smoker quitting as 35-year-old are €7,600 in men and €12,200 in women.
- All ex-smokers who quit smoking at the age of 35–55 years generate sizeable total lifetime cost savings.
- Smoking should be discouraged not only from a public health perspective but also from an economic perspective.
References


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