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ORIGINAL PAPER

Estimating the social cost of respiratory cancer cases attributable to occupational exposures in France

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Abstract

Purpose The objective of this article was to estimate the social cost of respiratory cancer cases attributable to occupational risk factors in France in 2010.

Methods According to the attributable fraction method and based on available epidemiological data from the literature, we estimated the number of respiratory cancer cases due to each identified risk factor. We used the cost-of-illness method with a prevalence-based approach. We took into account the direct and indirect costs. We estimated the cost of production losses due to morbidity (absenteeism and presenteeism) and mortality costs (years of production losses) in the market and nonmarket spheres.

Results The social cost of lung, larynx, sinonasal and mesothelioma cancer caused by exposure to asbestos, chromium, diesel engine exhaust, paint, crystalline silica, wood and leather dust in France in 2010 were estimated at between 917 and 2,181 million euros. Between 795 and 2,011 million euros (87–92 %) of total costs were due to lung cancer alone. Asbestos was by far the risk factor representing the greatest cost to French society in 2010 at between 531 and 1,538 million euros (58–71 %), ahead of diesel engine exhaust, representing an estimated social cost of between 233 and 336 million euros, and crystalline silica (119–229 million euros). Indirect costs represented about 66 % of total costs.

Conclusion Our assessment shows the magnitude of the economic impact of occupational respiratory cancers. It allows comparisons between countries and provides valuable information for policy-makers responsible for defining public health priorities.

Keywords Cost · Occupational health · Respiratory tract neoplasms · Asbestos · Cost of illness

JEL Classification D61 · H51 · H55 · I18 · J24 · J28 · J32

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Background

Prevention of occupational cancer is a major challenge in terms of public health but also in terms of social inequalities in health. Occupational exposures explain half of the differences in mortality from lung cancer in industrialized countries [1, 2]. Moreover, occupational health and safety have an impact on economic growth by affecting the labor supply, in particular through the number of working days lost because of illness or accident and the reduced productivity of employees at work. In addition, the labor supply of senior personnel and the trade-off for workers between additional years at work and pension benefits are determined by occupational health and working conditions [3, 4].

Cost-of-illness studies on cancer diseases are available in the literature [5–12], but very little literature has been devoted to the estimation of the cost of occupational cancers. The indirect and direct cost of occupational cancers in the USA was estimated at between 7,030 and 11,717 million dollars for the year 1992 [13]. Also in the USA, the medical cost of occupational cancers was assessed at 4,300 million dollars for the year 1999 [14] and 4,100 million dollars for the year 2007 [15]. Recently, Garcia Gomez et al. [16] estimated the direct costs of lung occupational cancer at 61,2 million euros for diagnosis and treatment in Spain for the year 2008. None of these studies, however, provides estimates of cost by risk factor.

The costs of occupational cancers can be estimated on the basis of the value of workers' claims related to cancer diseases. However, the workers' claims amounts depend on national legislative frameworks and insurance systems and make it difficult to compare estimates between countries. Evaluating the costs of occupational diseases based on workers' compensation can lead to underestimates. Diseases are not systematically declared by workers or physicians [17–19], and are not always covered by social welfare or insurance policies [20–23].

Another way to estimate the costs of diseases imputable to occupational exposures is the attributable fractions model. It has been widely used in the literature to estimate the burden of diseases in terms of morbidity and mortality [24–29]. Such estimates have been produced for occupational cancers [30–32]. This model can also be used to estimate the economic burden of diseases imputable to occupational exposures in monetary terms. The literature remains very sparse on this issue, except for some studies on the costs of diseases imputable to work stress [33] and the costs of occupational diseases and injuries in the USA [15, 34, 35].

As a result, no detailed estimation of the costs of occupational cancers by risk factor is available in the literature. However, such evaluations produce useful measures of the magnitude of the economic burden of carcinogenic exposures at work. Precise and detailed evaluations of the costs of cancer diseases attributable to occupational exposures are extremely valuable in providing guidance to policy makers when defining public health priorities and allocating limited resources for prevention [36].

The aim of this article was to estimate the costs of cancer attributable to occupational exposures from a societal perspective in France for the year 2010, according to a prevalence-based and cost-of-illness approach [37, 38]. We restricted the scope of the study to respiratory cancers because inhalation is the primary route of penetration of carcinogens in the workplace [30].

Methods and data

Attributable fractions data

We restricted our study to respiratory cancers as defined by the International Statistical Classification of Diseases and Related Health Problems (ICD). We therefore included larynx cancer (ICD10: C32), lung cancer (C33-34), sinonasal cancer (C30-31) and pleural mesothelioma (C45, C38.4). We included risk factors for which workers' compensation from the French national insurance is possible for a respiratory cancer as well as those that are ranked 1 or 2A by the International Agency for Research on Cancer, that is to say proven or probable carcinogens. We finally identified 24 risk factors of respiratory cancers.

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Lung cancer
Acrylamide
Alpha-chlorinated toluenes (benzal chloride, benzotrichloride, benzyl chloride) and benzoyl chloride (combined exposures)
Arsenic and inorganic arsenic compounds
Art glass, glass containers and pressed ware (manufacture of)
Asbestos
Beryllium and beryllium compounds
Cadmium and cadmium compounds
Chromium (VI) compounds
Cobalt metal with tungsten carbide
Crystalline silica
Diesel engine exhaust
Epichlorohydrin
Ionizing radiation (all types)
Nickel compounds
Nitrosamines, especially n-nitrosodimethylamine and n-nitrosodiethylamine
Non-arsenical insecticides (occupational exposures in spraying and application of)
Painter (occupational exposure as a)
Passive smoking
Polycyclic aromatic hydrocarbon
Rubber manufacturing industry
Strong-inorganic-acid mists containing sulfuric acid
Tetrachloroethylene (perchloroethylene)
Sinonasal cancer
Chromium (VI) compounds
Epichlorohydrin
Leather dust
Nickel compounds
Wood dust
Larynx cancer
Asbestos
Polycyclic aromatic hydrocarbon
Strong inorganic acid mists containing sulfuric acid
Pleural mesothelioma
Asbestos

As defined by Nurminen and Karjalainen [28], attributable fractions (AF) are an estimate of the fraction of cases that is "attributable to an exposure in a population and that would not have been observed if the exposure had been non-existent." They are based on relative risk (RR) estimates and prevalence of exposure estimates *P*e.

$$AF = \frac{P_e(RR - 1)}{P_e(RR - 1) + 1}$$

The relative risk assesses the intensity of an association between a risk factor and a disease, and the prevalence of exposure is the proportion of individuals exposed to a risk factor in a population. An attributable fraction allows one to estimate the number of attributable cancer cases (including cases resulting in death) by multiplying the attributable fraction by the total number of cancer cases in the general population.

Asbestos is the only recognized risk factor for mesothelioma cancers. The French National Mesothelioma Surveillance Program lists mesothelioma cases in France and directly assessed the attributable fraction to asbestos at 38.4 % for women and 83.2 % for men [39]. For this disease, we directly used estimates of the attributable fraction produced by this survey, since these data were specific to France. For other types of cancer, relative risk estimates were derived from a systematic review of meta-analytical studies for each risk factor using MEDLINE. We focused on studies published from January 1990 to April 2011 and written in French or English. From the results of this research, we first excluded the studies that were not meta-analytical studies or that did not assess the intensity of an association between a risk factor and a disease. We then excluded the studies for which population, risk factor or disease was not relevant.

Estimates of prevalence exposure came from the Matgéné survey [40–43] or, when no data were available, were estimated from the SUMER (Surveillance Médicale des Risques Professionnels) survey [44]. Matgéné and SUMER do not provide exposure data for painters. In this particular case, we estimated the prevalence exposure for painters considering that all individuals belonging to the socio-professional category "painters and skilled workers in laying coatings on vertical supports" from the annual declaration of social data [45] were exposed. This assumption led to a low value of prevalence exposure because all painters may not belong to this socio-professional category and because individuals from others professions may be exposed to paint.

Studies from the literature review provide relative risk data for 10 of the 24 identified risk factors. The SUMER and Matgéné surveys do not provide prevalence of exposure data for passive smoking, polycyclic aromatic hydrocarbons and the rubber industry. On the basis of the available data, we estimated the attributable fractions for seven risk factors, namely asbestos, chromium, crystalline silica, diesel engine exhaust, paint, leather and wood dust (see Table 1). We produced a range of attributable fractions values. AF low-range values were calculated using low-range values of relative risk and AF high-range values were calculated using high-range values of relative risk.

The number of deaths from lung and larynx cancer in 2010 was derived from the literature [46]. Data from the Center for Epidemiology on Medical Causes of Death (CépiDc) for the years 2000–2008 showed a linear progression in the number of deaths from sinonasal or mesothelioma cancer in France [47]. For these two types of cancer, we estimated the deaths in 2010 using the ordinary least squares method.

Colonna et al. [48] estimated the numbers of prevalent cases of lung, larynx and mesothelioma cancers in 2002 and in 2012. We estimated the number of prevalent cases in 2010 for these cancers from a linear interpolation. No recent data were available for sinonasal cancer. We applied a ratio "lung cancer incidence/sinonasal cancer incidence", estimated by Autier et al. [32], to the number of incident cases of lung cancer for the year 2010 in order to estimate the number of incident cases of sinonasal cancer for 2010 in France. Due to lack of data, we assumed that the number of prevalent cases of sinonasal cancer was equal to the number of incident cases.

Cost data

The method commonly used to estimate the impact of illnesses at the social level is the so-called "cost Of illness" method. This attempts to measure all the various consequences of the disease in monetary terms [49], in other words, the amount of limited resources consumed because of illness [50].

Direct medical costs

To evaluate the direct medical cost of lung, larynx, sinonasal and mesothelioma cancers for the year 2010 in France, we used the study by Amalric [51], which was itself based on the pioneering work of Borella et al. [52, 53].

Borella et al. created an algorithm to extract cancer-related hospitalizations from the program for medicalization of the information systems (PMSI) database in France. The PMSI is based on exhaustive collection of medical information concerning the stay of all patients treated by hospitals. This information comes from data collection of diagnoses and procedures and is classified in diagnosis-related groups. The hospital stays extracted by Borella et al. from the PMSI database were valued using the French national study on costs. This study, based on a sample of

Table 1 Prevalence of exposure, relative risk data and estimates of the fractions of diseases attributable to risk factors for 2010 in France

Disease	Risk factor	Gender	Prevalence of exposure (%)	Relative risk		Attributable fraction	
				Low value	High value	Low value (%)	High value (%)
Larynx cancer	Asbestos	Women	2.70	1.33	1.57	0.88	1.52
		Men	26.70			8.10	13.21
Lung cancer	Asbestos	Women	2.70	1.48	3.1	1.28	5.37
		Men	26.70			11.36	35.93
	Chromium	Women	0.60	1.18	1.41	0.11	0.25
		Men	2.70			0.48	1.09
	Crystalline silica	Women	0.75	1.22	1.42	0.16	0.31
		Men	15.60			3.32	6.15
	Diesel engine exhaust	Women	1.20	1.33	1.47	0.39	0.56
		Men	21.00			6.48	8.98
	Painter	Women	0.06	1.22	2.04	0.01	0.06
		Men	1.32	1.22	1.57	0.29	0.75
Pleural mesothelioma	Asbestos	Women	–	–	–	38.40[a]	–
		Men	–	–	–	83.20[a]	–
Sinonasal cancer	Leather dust	Women	4.50	2.71	–	7.15	–
		Men	2.20	1.92	–	1.98	–
	Wood dust	Women	0.9	1.17	3.1	0.15	1.85
		Men	10.80	2	3.9	9.75	23.85

[a] *Source*: Goldberg et al. [39]

health establishments [54], estimates an average cost per diagnosis-related group. These costs include direct spending of patients (medical procedures), spending related to stays but also related to catering, laundry, logistics, administration or the establishment structure (amortization, financial expenses, etc.). Amalric [51] produced updated data for 2004 and added the cost of private radiotherapy, expensive cancer drugs, specific subsidies for innovative treatments and non-hospital care specific to cancer.

Data were available for upper aerodigestive tract cancers, including sinonasal and larynx cancers, and respiratory system cancers, including lung and mesothelioma cancers. We first estimated the direct cost of all upper aerodigestive tract and respiratory system cancers for 2010.

To assess the costs of stays and private radiotherapy for 2010 in France, we updated the 2004 estimates taken from Amalric's study and took account of the change in the average cost of corresponding diagnosis-related groups between 2004 and 2010.

Amalric [51] estimated the share of specific subsidies for innovative treatments related to cancer at 10.5 % and the share of funding of cancer-related research at 26 % for the year 2004. Using data for the year 2010 [55], we estimated the amount of specific subsidies for innovative cancer-related treatments excluding the funding of research.

The costs of expensive drugs are available for all cancers for the year 2010 [56]. We assumed that the distribution of these costs across the main sites of cancer was the same in 2010 as in 2004.

Due to the lack of data, other direct healthcare costs (other than hospital costs) were estimated directly from the direct hospital costs. These include ambulatory care, medicines and other medical goods and represent 29 % of the total direct cost for respiratory system cancers and 32 % for upper aerodigestive tract cancers [51].

The average direct cost can then be approximated by dividing the direct cost for a cancer site by the corresponding number of incident cases for the same year [57]. We used this methodology to estimate an average cost per case and by cancer location. Due to lack of data, we assumed that the average direct cost of lung and mesothelioma cancers was equal to the average direct cost of respiratory system cancers and that the average cost of sinonasal and larynx cancers was equal to the average cost of upper aerodigestive tract cancers.

We estimated annual average direct costs at €33,422 for lung and mesothelioma cancers and at €36,476 for larynx and sinonasal cancers in France (see Table 2).

Indirect costs

Indirect costs consist of production losses due to sick leaves and premature deaths caused by the disease or its treatment [37] as well as presenteeism. Presenteeism occurs when workers are physically present but function at

Table 2 Estimates of the average annual direct cost per patient

Disease	Average per-patient annual hospital costs					Average other annual healthcare costs per patient	Average annual direct cost per patient
	Cost of stays	Private radiotherapy	Expensive drugs	Specific subsidies for innovative treatments	Total		
Pleural mesothelioma and lung cancer	19,500	866	2,966	397	23,730	9,692	33,422
Sinonasal cancer and larynx cancer	21,344	2,925	0	535	24,804	11,672	36,476
Estimation method	Updated from Amalric et al. [51]		Estimated from Mourlat et al. [56]	Estimated from Jegou [55]		Estimated from total hospital costs	
Key assumptions made in our evaluation	According to the change in the average cost of corresponding DRG		Same distribution of cost across the main sites of cancer in 2004 and in 2010	10.5 % of SSIT are related to cancer and 26 % of these subsidies are related to research on cancer		Other healthcare costs represent 29 % of total cost for pleural mesothelioma and lung cancer and 32 % of total cost for sinonasal and larynx cancer	

DRG diagnosis-related group, *SSIT* specific subsidies for innovative treatments

less than full productivity because of illness [58]. Indirect costs can represent a very large proportion of total costs. Weissflog et al. [8] argue that such indirect costs of lung cancer in Germany accounted for 89 % of total costs.

Indirect costs are often underestimated because they are usually restricted to market production losses related to absence from work only. We included indirect costs due to nonmarket production and also to presenteeism. We distinguished between morbidity (absenteeism and presenteeism) and mortality costs in the market and nonmarket spheres.

To take account of all these categories of indirect costs without the risk of double counting, we created a decision tree in order to estimate the probability of any given case being assignable to each cost category and included this parameter in our evaluation models. To develop the decision tree, we used specific data on activity and employment rates for patients with cancer as well as data on the impact of cancer on their working lives (see Fig. 1).

Malavolti et al. [59] provided estimates for lung and upper aerodigestive tract cancers in terms of the percentage of individuals assigned to four categories 2 years after diagnosis in the year 2004: persons who lost or left their employment, those who returned to work, those who remained in employment without interruption and those who never returned to work. We assumed that individuals who never returned to work after 2 years corresponded to the population affected by long-term absences. We also assumed that those who returned to work were affected by short-term absences. We considered that the data on employment status were applicable to the year 2010.

To assess absenteeism costs, we assumed that short-term absence corresponds to the average number of sick leave days per year. We defined a long-term absence as an absence of over 1 year. There is no consensus in the literature on the valuation method that should be adopted when estimating absenteeism costs. We chose to assess these costs using both the “friction cost” method and the “human capital” method in order to compare the results of these two approaches.

The “human capital” method estimates the costs of absenteeism on the basis of the production that the individual would have been able to generate if he or she had been alive and healthy [60]. To estimate production losses, the number of working hours lost is multiplied by the gross wage plus the employer’s social contributions [37].

The “friction cost” approach is based on the assumption that after a certain period of time, called the friction period, ill workers can be replaced at work by unemployed workers since the economy is not at full employment state [61, 62]. The friction period corresponds to the time required to recover the initial level of productivity [63]. The friction cost approach also assumes that the elasticity

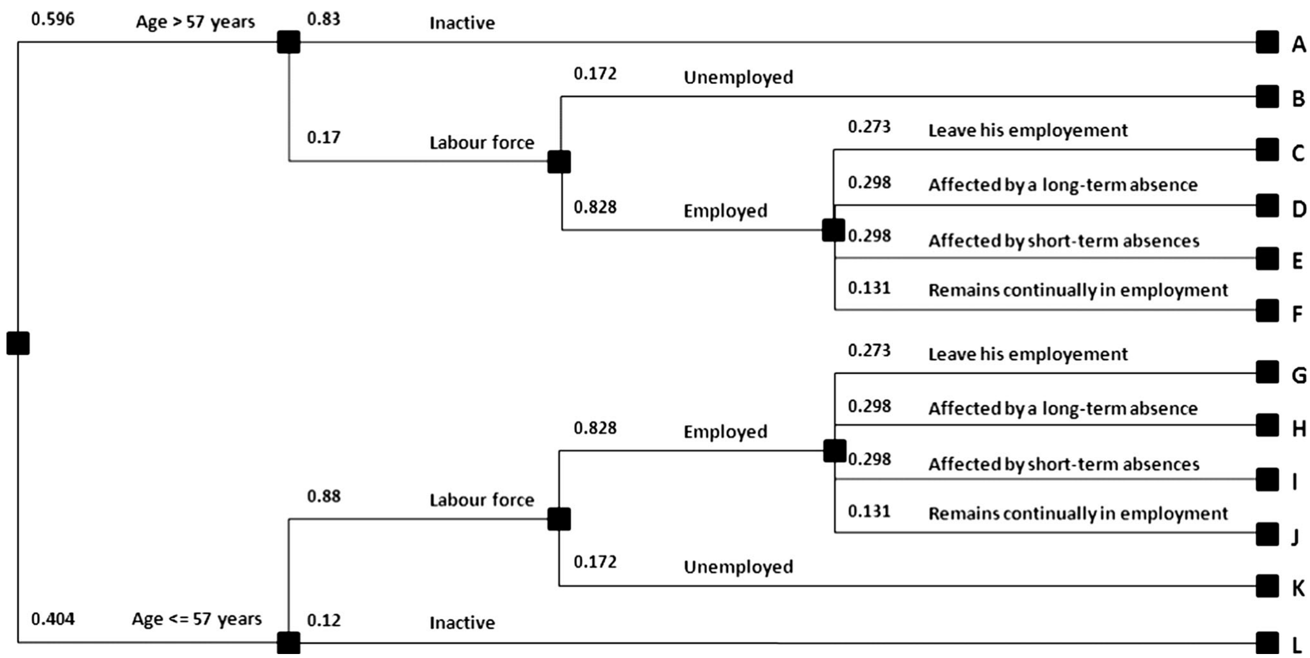

Fig. 1 Decision tree to estimate the probabilities of being affected by each event. *Reading guide* Example 1: Among employed individuals, 27.3 % would leave their employment following a respiratory cancer diagnosis. Example 2: The probability of being in situation C is 2.29 % (0.596 × 0.17 × 0.828 × 0.273 = 0.029). This corresponds to the probability of being older than 57 years AND being active AND employed AND leaving employment after a diagnosis of respiratory cancer

of production to working time is not equal to 1. The proponents of this approach argue that the production of the absent employee is not totally lost. The absence of an employee, if it is short, can sometimes be partially or completely offset by an increase in the work done by his colleagues. The individual who was absent from work for a time can also catch up all or part of the delay when he returns. We chose the commonly used assumption of a loss of only 80 % of production [63].

The duration of the friction period has been estimated at between 2.8 and 3.2 months in The Netherlands [63] and between 2.5 and 3.5 months in Spain [64]. We retained the low estimate of 2.5 months (75 days) for our analysis and, due to lack of data, we also assumed that the average number of sick leave days per year is equal to the friction period in accordance with the methodology developed by Amalric [51].

To estimate the annual value of production losses according to the human capital method, we multiplied the average number of sick leave days per year *A* by the daily value of production losses based on the gross domestic product per capita in France and per day GDP_{cd} in 2010, as in formula (1).

$$\mathrm{IC}(A)_{ab} = \mathrm{GDP}_{cd} \times A \times \mathrm{PR}_{ab} \times p(A) \quad (1)$$

here $\mathrm{IC}(A)_{ab}$ represents the indirect costs of short or long-term absences from work for disease a attributable to risk factor b.

p(A) is the probability of being affected by short- or long-term absences from work in the decision tree (Fig. 1, situations E, I, D and H), and PR_{ab} is the number of prevalent cases of disease a attributable to risk factor b.

Our study shows that the annual market value of lost production due to a long-term absence is €43,614 according to the human capital approach and €10,903 according to the friction cost approach.

The annual market value of lost production due to short-term absences was evaluated at €13,629 according to the human capital approach and €10,903 according to the friction cost approach.

Presenteeism occurs when workers are physically present but function at less than full productivity because of illness [58]. Goetzel et al. [65] estimated that presenteeism due to cancer costs an average of 8.5 % *(P)* of annual production in the USA. We estimated the value of market production per individual at €43,614 in 2010, based on GDP per capita per year GDP_{cy}. We therefore estimated the annual value of market production losses in the case of presenteeism at €3,563. Indirects costs due to presenteeism IC*(P)* were estimated using formula (2):

$$\mathrm{IC}(P)_{ab} = \mathrm{GDP}_{cy} \times P \times \mathrm{PR}_{ab} \times p(P) \quad (2)$$

where *p(P)* is the probability that presenteeism will occur (Fig. 1, situations D, E, F, H, I and J), and GDP_{cy} is the gross domestic product per capita and per year in France in 2010.

We evaluated the indirect costs in the nonmarket sphere for individuals without employment. Data on the number of domestic work hours performed by individuals were derived from the study of Roy et al. [66, 67]. We chose not to use the most restrictive definition of domestic activities because we focused on individuals without employment. Instead, we used the median definition that includes essential tasks such as cleaning or washing dishes as well as activities such as do-it-yourself or gardening.

The time spent on domestic activities per day was estimated at 3 h and 17 min, which corresponds to an average of 1,197.2 h per year, valued at €8.86 per hour (hourly minimum wage in 2010) according to the replacement cost approach. The value of non-market production losses per year NM_y was estimated at €10,607 per person.

$$\mathrm{IC(NM)}_{ab} = \mathrm{NM}_y \times \mathrm{PR}_{ab} \times P(\mathrm{nojob}) \quad (3)$$

where $\mathrm{IC(NM)}_{ab}$ represents the indirect costs in the nonmarket sphere for disease a attributable to risk factor b, and P(nojob) is the probability of not having a job (Fig. 1, situations A, B, C, G, K and L).

To estimate the costs of years of life lost because of death, we used the number of death data D provided by the center of epidemiology on medical causes of death (CépiDc) for 2008 for each cancer site. We assumed that the age distribution of deaths in 2010 was identical to that in 2008.

The average retirement age R being 61.62 years [68], we computed the number of years lost R-j for each age group j. We took account of an annual growth of GDP g and a discount rate r, as in formula (4). We used a growth rate of 2 % and a discount rate of 5 % as reported in the literature [37].

$$\mathrm{IC(YLL)}_{ab} = \mathrm{GDP}_{cy} \times p(E) \times \sum_{j}^{R}\left(D_{\mathrm{abj}} \times \sum_{y=1}^{R-j}\frac{(1+g)^y}{(1+r)^y}\right) \quad (4)$$

Here $\mathrm{IC(YLL)}_{ab}$ represents the indirect costs of years of life lost in the market sphere for disease a attributable to risk factor b, and $p(E)$ is the probability of being employed (Fig. 1, situations C, D, E, F, G, H, I and J).

To estimate the indirect costs of mortality in the nonmarket sphere, we must consider two distinct situations. If the individual was not employed at the time of death, resulting production losses only affected the nonmarket sphere and were measured between each age group of death j and life expectancy LE as in formula (5). If the individual was in employment, nonmarket production losses corresponded to the years of life lost between retirement age R and life expectancy, as in formula (6). Life expectancy in 2010 was estimated at 78.1 years for men and 84.8 years for women.

$$\mathrm{IC(YLL)}_{ab} = \mathrm{NM}_y \times p(\mathrm{UI}) \times \sum_{j}^{\mathrm{LE}}\left(D_{\mathrm{abj}} \times \sum_{y=1}^{\mathrm{LE}-j}\frac{1}{(1+r)^y}\right) \quad (5)$$

$$\mathrm{IC(YLL)}_{ab} = \mathrm{NM}_y \times p(E) \times \sum_{j=R}^{\mathrm{LE}}\left(D_{\mathrm{abj}} \times \sum_{y=1}^{\mathrm{LE}-j}\frac{1}{(1+r)^y}\right) \quad (6)$$

here $\mathrm{IC(YLL)}_{ab}$ represents the indirect costs of years of life lost in the nonmarket sphere for disease a attributable to risk factor b, and p(UI) is the probability of being unemployed or inactive at the time of death (Fig. 1, situations A, B, K and L).

We performed a sensitivity analysis to test the sensitivity of our results, in terms of social costs, to a change in the main parameters of our evaluation: length of the friction period, number of days of sick leave per year, GDP growth rate, discount rate and definition of domestic activities.

Results

We estimated the number of prevalent cases of lung cancer due to exposure to asbestos at between 4,201 and 13,405, to diesel engine exhaust at between 2,367 and 3,283, and to crystalline silica at between 1,209 and 2,241 for the year 2010 (see Table 3). The numbers of deaths from lung cancer attributable to exposure to asbestos and to diesel engine exhaust were estimated respectively at between 2,749 and 8,777, and at between 1,548 and 2,146 for the same year.

The results are presented in Table 4 for each risk factor, cancer site and type of cost. The low range corresponds to the low estimate of the number of prevalent cases or deaths and to the use of the friction cost method to value indirect costs of absenteeism. The high range is based on the high estimate of the number of prevalent cases or deaths and the use of the human capital approach.

We estimated the social cost of respiratory cancer due to exposure to asbestos at between 415 and 1,380 million euros, to diesel engine exhaust at between 233 and 336 million euros, and to crystalline silica at between 119 and 229 million euros for the year 2010. The estimate of indirect costs for respiratory cancer due to exposure to asbestos is 334–1,012 million euros, whereas the estimate of direct costs is 197–527 million euros.

Table 3 Estimates of morbidity and mortality prevalent cases attributable to each risk factor for the year 2010

Disease	Risk factor	Gender	Number of attributable cases	
			Morbidity	Mortality
Larynx cancer	Asbestos	Women	12–20	1–2
		Men	956–1,559	72–118
Total for larynx cancer			968–1,579	73–120
Lung cancer	Asbestos	Women	113–475	80–336
		Men	4,088–12,930	3,669–8,441
		Total	4,201–13,405	2,749–8,777
	Chromium	Women	10–22	7–15
		Men	174–294	114–257
		Total	184–316	121–272
	Crystalline silica	Women	15–28	10–20
		Men	1,194–2,213	780–1,445
		Total	1,209–2,241	790–1,465
	Diesel engine exhaust	Women	35–50	25–35
		Men	2,332–3,233	1,523–2,111
		Total	2,367–3,283	1,548–2,146
	Painter	Women	1–6	1–4
		Men	104–269	68–175
		Total	105–275	69–179
Total for lung cancer			8,066–19,520	5,277–12,839
Pleural mesothelioma	Asbestos	Women	94	91
		Men	542	576
Total for pleural mesothelioma			636	667
Sinonasal cancer	Leather dust	Women	24	4
		Men	10	3
		Total	34	7
	Wood dust	Women	1–5	0–1
		Men	50–122	13–33
		Total	51–127	13–34
Total for sinonasal cancer			85–161	20–41

Discussion and conclusion

According to the prevalence-based approach, the social cost of lung, larynx, sinonasal and mesothelioma cancer caused by exposure to asbestos, chromium, diesel engine exhaust, painters, crystalline silica, wood and leather dust in France totaled between 917 and 2,181 million euros for the year 2010. Between 795 and 2,011 million euros (87–92 %) of the total costs were due to lung cancer alone. Asbestos was by far the risk factor that represented the greatest cost to French society in 2010 (58–71 %), ahead of diesel engine exhaust (15–25 %) and crystalline silica (10–13 %). Indirect costs represented about 66 % of total costs.

We tested the sensitivity of our estimates of social cost by successively modifying the main parameters of our assessment models. The impact of the variation of these parameters on the estimates of social cost was almost similar for all risk factors. Asbestos is the risk factor with the most important economic impact on society. We therefore chose to present here the results of the sensibility analysis for the social cost of lung cancer due to exposure to asbestos.

Changing the length of the friction period or the number of days of sick leave per year from 75 to 105 days has a negligible impact on the result. An increase in GDP growth rate from 2 to 5 % raises the social cost by 6.3–8.1 %. The choice of discount rate is important in our assessment since changing from a rate of 5–3 % increases the social cost by 14.2 %. The social cost of lung cancer attributable to asbestos falls by 11.8–12.3 % if we use the restrictive definition of domestic activities and increases from 9.8 to 10.2 % if we use the extensive definition of domestic activities.

There are few data on the number of cancer cases attributable to occupational exposure in France to compare

Table 4 Social costs of lung, larynx, mesothelioma and sinonasal cancer attributable to occupational risk factors in 2010 (in thousands of euros)

Disease	Risk factor	Gender	Direct costs		Indirect costs		Total costs €		%	
			Low value	High value	Low value	High value	Low value	High value	Low value	High value
Lung cancer	Asbestos	Women	3,777	15,875	10,650	46,631	14,427	62,507	3	5
		Men	136,629	432,146	263,620	885,389	400,249	1,317,536	97	95
		Total	140,406	448,022	274,270	932,021	414,676	1,380,043	100	100
	Chromium	Women	334	735	933	2,094	1,267	2,829	7	7
		Men	5,815	9,826	11,253	25,450	17,069	35,276	93	93
		Total	6,150	10,561	12,186	27,544	18,336	38,105	100	100
	Diesel engine exhaust	Women	1,170	1,671	3,325	4,865	4,494	6,536	2	2
		Men	77,941	108,055	150,420	221,416	228,361	329,471	98	98
		Total	79,111	109,726	153,745	226,281	232,856	336,007	100	100
	Painters	Women	33	201	129	560	162	761	2	3
		Men	3,476	8,991	6,715	18,370	10,191	27,361	98	97
		Total	3,509	9,191	6,843	18,930	10,353	28,122	100	100
	Crystalline silica	Women	501	936	1,341	2,772	1,842	3,707	2	2
		Men	39,906	73,964	77,034	151,561	116,940	225,525	98	98
		Total	40,408	74,900	78,375	154,333	118,782	229,232	100	100
Total for lung cancer		Women	5,815	19,418	16,377	56,922	22,193	76,341	3	4
		Men	263,768	632,981	509,042	1,302,187	772,810	1,935,168	3	96
		Total	269,583	652,400	525,419	1,359,109	795,002	2,011,508	100	100
Larynx cancer	Asbestos	Women	438	730	239	513	677	1,243	1	1
		Men	34,871	56,866	17,253	34,417	52,124	91,283	99	99
Total for larynx cancer			35,309	57,596	17,492	34,930	52,801	92,526	100	100
Mesothelioma cancer	Asbestos	Women	3,132	3,132	7,785	8,159	10,916	11,290	17	17
		Men	18,130	18,130	34,251	36,418	52,381	54,548	83	83
Total for mesothelioma cancer			21,262	21,262	42,035	44,577	63,297	65,839	100	100
Sinonasal cancer	Leather dust	Women	863	863	753	848	1,616	1,711	70	70
		Men	369	369	327	367	696	736	30	30
		Total	1,232	1,232	1,080	1,215	2,312	2,447	100	100
	Wood dust	Women	36	182	22	190	58	372	2	4
		Men	1,824	4,450	1,574	4,428	3,398	8,878	98	96
		Total	1,860	4,632	1,596	4,618	3,456	9,250	100	100
Total for sinonasal cancer		Women	899	1,045	775	1,038	1,674	2,083	29	18
		Men	2,193	4,819	1,901	4,795	4,094	9,614	71	82
		Total	3,092	5,864	2,676	5,833	5,768	11,697	100	100
Total for all cancers		Women	10,284	24,324	25,176	66,632	35,459	90,956	4	4
		Men	318,962	712,797	562,447	1,377,817	881,409	2,090,614	96	96
		Total	329,246	737,121	587,622	1,444,449	916,868	2,181,570	100	100

our results with the literature. For the year 2010, we estimated the number of deaths from lung cancer due to exposure to asbestos at between 2,749 and 8,777. This result is consistent with the literature. Imbernon [30] estimated the number of deaths from lung cancer attributable to exposure to asbestos in France at between 2,086 and 4,172 for the year 1999.

Since this study is the first to provide results concerning the social cost of occupational respiratory cancers in France, it is difficult to compare our estimates with estimates from the literature that do not take into account the same types of costs, are not assessed for the same year or in the same country. We estimated the direct costs of lung cancers attributable to occupational exposure at between 270 and 652 million euros for the year 2010 in France. The direct costs of occupational lung cancers was estimated at 1,380 million dollars for the year 2007 in the USA [15] and at 61,2 million euros for the the year 2008 in Spain [16].

It is possible to compare some of our intermediate results in terms of costs with the literature. We estimated the annual average hospital costs at €23,730 for lung cancer and pleural mesothelioma, and €24,804 for sinonasal and larynx cancers. The average hospital cost of lung cancer in 1999 in France was estimated at between $20,691 and $31,833 over an 18-month period depending on the histological type of cancer [69] and at €22,006 over a period of 12 months [70]. The average annual expenditure for lung cancer, whether bronchial or tracheal, recognized as a long-term illness was estimated at €17,491 in 2003 [71]. Our estimates of annual average hospital costs are of the same order of magnitude as those available in the literature that generally take into account the cost of hospital stays but not specific subsidies for innovative treatments or expensive drugs.

As far as estimates of production losses due to absenteeism are concerned, indirect costs for short-term absences are 1.25 times higher when the human capital method rather than the friction cost method is used. Indirect costs estimated using the human capital approach are generally higher than those estimated by the friction cost method. Depending on the cost estimated and the methodology used, the cost may be, for example, 3 times [50] or 69 times higher when the human capital approach is used [72]. We assumed that the average number of days off work per year is equal to the friction period. The smaller gap in our study can be explained by the fact that the only difference between the two approaches with regard to short-term absences lies in the fact that the the friction cost approach assumes a loss of production of only 80 %.

In the case of long-term absences, the estimated cost is four times higher when the human capital method is used. The differences between the estimates obtained using the human capital approach and the friction cost method are both consistent with the literature (see above) and natural given the method of calculation. Indeed, unlike the human capital method, the friction cost method assumes that the absent or deceased employee no longer represents any cost to society after the friction period has elapsed.

Some limitations to this study must be pointed out. For several reasons, our estimation of the costs of respiratory cancers due to occupation exposure is rather conservative.

We could not include all the risk factors of respiratory cancers in our estimates because of a lack of prevalence of exposure data. The link between lung cancer and nickel, arsenic [73] or polycyclic aromatic hydrocarbons [74, 75] is however well established in the literature.

The evaluation of the indirect costs of morbidity related to presenteeism was based on the estimated annual loss of productivity due to cancer of 8.5 % taken from Goetzel et al. [65]. Lung and mesothelioma cancers have a very grim prognosis. The decline in work productivity of patients with these cancers is certainly greater than that of patients with other cancers. Using the average value of 8.5 % probably led to an underestimation of the social cost of lung and mesothelioma cancers due to presenteeism.

The social cost of lung, sinonasal, larynx and mesothelioma cancer due to the studied risk factors was underestimated in our analysis because we made the methodological choice of taking account only of direct and indirect costs. We did not estimate the intangible costs, which probably represent a significant proportion of the social cost given the large number of deaths and the estimates of the statistical value of human life which vary between 0.5 and 50 million dollars [76].

The number of prevalent sinonasal cancer cases was not available in the literature. We therefore assumed that it is equal to the number of incident cases for the year. This assumption probably resulted in an underestimate of the cost of sinonasal cancers because, according to the Eurocare database, the survival rate at 5 years is 50.04 % for sinonasal cancer. For lack of more precise data, our estimates of the social cost of sinonasal cancers attributable to wood and leather dust were based on these assumptions.

We estimated the number of prevalent cases of sinonasal cancer due to exposure to wood dust at between 50 and 122 for men and at between 1 and 5 for women for the year 2010. The number of deaths from sinonasal cancer was estimated at between 13 and 33 for men and at between 0 and 1 for women. The risk of sinonasal cancers attributable to wood dust exposure is probably highly underestimated. Our estimates of sinonasal cancers attributable to wood dust exposure were based on RR data varying between 1.17 [29] and 3.9 [77]. These estimates of RR were derived from multicenter studies and do not take into account the specificity of the French context in which the use of hardwood is more common, especially in the manufacture of furniture [78]. Imbernon [30] chose an RR of 10 as a conservative range value to estimate the risk of sinonasal cancer due to wood dust in France. Our assessment did not take into account this specificity since our RR estimate varied between 1.17 and 3.9. If we based our estimates on a RR value of 10, the number of prevalent cases of sinonasal cancer due to exposure to wood dust would be estimated at 251 for men and 19 for women, and the number of deaths at 68 for men and 4 for women for the year 2010. This would have an important impact on the high range value of social cost of sinonasal cancer due to exposure to wood dust, which would rise from 372,000 euros to 1,438,000 euros for women and from 8,878,000 euros to 18,274,000 euros for men. However, using an RR value of 10 would have a low impact on the total cost of all occupational respiratory cancers, which would rise by only 0.48 %.

The aim of our study was to evaluate the social cost of cancers attributable to occupational risk factors. We were therefore interested in the impact of these risk factors on cancer alone. However, each risk factor can cause diseases other than cancer that we did not take into account here. These diseases may cause medical expenses, absenteeism at work, death or suffering.

This study also has several strengths. We present the results in the form of a low estimate, which corresponds to low estimates of attributable risks and the use of the friction cost method for valuing indirect costs of absenteeism in the market sphere, and a high estimate, based on high values of attributable risks and which makes use of the human capital method.

The data we used are highly consistent, since the relative risk estimates, prevalence of exposure data and cost data are based on the same definition of the disease. We also provided data for each gender separately. The cancer prevalence data are of high quality, since they are based on national statistics. Moreover, we provided detailed data on each cancer site, for each risk factor, and our estimates of indirect costs take account of both market and non-market production.

This is the first study to examine the social costs of respiratory cancers attributable to occupational risk factors in France.

Cancer is a disease that is still difficult to treat and that can have physical as well as psychological repercussions. The occupational risk factors are generally "avoidable" with technically feasible preventive measures being available, whose implementation, however, depends on decisions made by individuals not directly affected by these risks. In the particular context of occupational cancers, it is ultimately more effective to prevent a cancer than to treat it.

The production of data on the cost of occupational cancers is essential but unfortunately very rare in France. Our assessment shows the magnitude of the economic impact of occupational respiratory cancers. It makes it possible to perform comparisons between countries and provides valuable information for policy-makers when defining public health priorities.

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