

ORIGINAL ARTICLE

GLOBAL ECONOMIC BURDEN OF ASBESTOS RELATED DISEASES IN COMPARISON WITH THE COSTS OF PRODUCTION AND CONSUMPTION

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ABSTRACT

Occupational cancers, including mesothelioma and lung cancer are linked to the use of asbestos. Annually, at least 100,000 global deaths are attributed to asbestos exposure putting a heavy burden on national budgets. Expenses incurred on treatment of asbestos related diseases (ARDs) reduce households and national resource savings, while ARDs culminate in terminal burdens. The objective of this study is to measure the economic burden of ARDs and to assess the economic impact of asbestos consumption. The health and economic burden of asbestos was estimated in macro-global consumption-production model using production function frontier-based and generalized least squared approach for asbestos products and cost tabulation. Production, in metric tons (Mt) was adopted as a dependent variable among explanatory variables, including consumption. Information on treatment cost of asbestos related diseases (mesothelioma, asbestosis and lung cancer) was obtained from costing information and published literatures. Annual total economic burden of asbestos is at USD 11.92 billion. Out of this cost, USD 4.34 billion per annum is the economic burden of managing three common ARDs. The cost of compensation for patients suffering ARDs is USD 4.28 billion. From the remaining USD 3.3 billion, USD 2.93 billion is the value of asbestos consumed in 2003 and USD372.15 million is the loss of earning due to hospital visits and admissions. For every USD 1 spent on consumption of asbestos, global economy has to absorb almost USD 4 due to health consequences of ARDs. Banning of asbestos production and usage in production of goods has far-reaching impacts on household welfare, health and economic development. The insights revealed are expected to inform decision makers the need to ban all forms of asbestos, especially in developing countries where usage is increasing.

Keywords: Cost, Development, Mesothelioma, Lung cancer, Savings, Welfare, Developing countries.

BACKGROUND

Asbestos is the most important occupational carcinogen responsible for causing nearly half of occupational cancer deaths¹⁻³. The historical and commercial use of asbestos is attributed to its tensile strength, large length-width ratio, flexibility and resistance to chemical and thermal breakdown. Asbestos is a poor electrical conductor and can be knitted into textiles⁴⁻⁷.

The varieties of asbestos consumed are actinolite, amosite, anthophyllite, chrysotile, crocidolite and tremolite. Chrysotile belongs to serpentine group while the remaining types are from amphibole group⁸⁻¹⁰. Chrysotile is the most used asbestos followed by crocidolite, amosite and anthophyllite¹¹.

The diseases linked to asbestos, such as mesothelioma, lung fibrosis, pleural plaques and lung as well as laryngeal cancers are caused by inhalation of asbestos fibers from contaminated workplace air during indoor activities or from buildings containing friable materials. Asbestos-related diseases (ARDs) can also be induced through drinking water from pipes made of asbestos, which poses water management challenges¹²⁻¹³. Health risks and exposure to asbestos can occur during installation, maintenance and use of asbestos-containing products, such as vehicles brakes and building tiles¹⁴⁻¹⁶.

The risk of mesothelioma increases with exposure time period and requires timely warning to prevent

explosion of ARDs and exposure to asbestos synergistically increases risks of lung cancer commonly among smokers. ARDs have high fatality rates, for instance mesothelioma has a median survival of 12 months after initial manifestation and patients often do not respond to medical treatment¹⁷⁻¹⁹.

The heavy burden of ARDs was attributed to rampant use of asbestos between 1960s and 1970s, however many countries banned use early 1990²⁰. Studies found that 125 million people were exposed to asbestos at the workplace and almost 107,000 could be dying every year²⁻³. ARDs are known to have a long latency period ranging from 20 to 50 years from exposure to manifestation. Mesothelioma mortality rate has been rising in developed countries over the past 20 years after sustained asbestos consumption. The burden of mesothelioma is characterized by short time span progress from manifestation to death. In United Kingdom, almost 2,000 deaths occur annually from asbestos exposure, and the predicted compensation cost is projected around USD 300 billion for the developed world¹⁸.

Global efforts to ban asbestos, European Union and World Health Organization recommend prohibition and ban on all forms of asbestos²⁰. However chrysotile is still consumed widely; with 90 percent used for asbestos-cement building materials, and trading trends have shifted to low and middle-income countries in Africa, Asia and Latin America²¹⁻²².

The widespread use of asbestos owes to low cost and false assurance provided by absence of symptoms within latency period, along with weak surveillance system to detect ARDs due to misinformation that is not cognizant of asbestos-related health risks in low and middle-income countries²²⁻²⁷. Moreover, miseries caused by ill health and death cannot be justified on basis of cheap asbestos inputs to improve incomes and reduce poverty. There is unresolved question as who will be responsible for health hazards caused to the public by dangerous waste left behind after mines cease operations or inappropriate disposal of depreciated items, indicating asbestos burden perpetuation to future generations. Besides this, are the countries in Asia ready to handle asbestos related health and economic burdens as there is low economic growths? [28]. At the same time, asbestos-related diseases observed in high-income countries are likely to arise in future among low and middle-income countries where asbestos continues to be used widely^{18,29,30}. In the context of hazards created by asbestos, this paper presents the development of macro global

consumption-production model, including the production function frontier-based estimate for asbestos products and cost analysis; for guiding decisions on stopping asbestos consumption to minimize associated health and economic burdens. We also intend to make a contribution needed to justify asbestos ban, as such information is inadequate. The insights revealed could be used for decisions making with regard to banning all forms of asbestos, especially in developing countries by the public health workers, policy-makers, government officials and local leaders.

METHODS

Modeling Asbestos Production

The data were collected from secondary sources including internet search of scientific databases such as 'Pubmed' and United States Geographical Survey (USGS) documents, and used production - consumption data from 1900 to 2003³⁰, because there is incomplete data on asbestos due to confidentiality involved in its use. We also assessed data distribution by normal probability-plot technique³¹. The underlying assumptions for checking normality included the assumption that data behaved as random drawings, from a fixed distribution with a fixed location and a fixed scale. However, researchers acknowledge that the error component in most common statistical models was the specific assumption of fixed location and a fixed scale; given that if one of the major assumptions of the model has been violated in analysis, the residuals from fitted model would not be normally distributed. Otherwise, adopting from Engineering Statistic Hand (ESH) the model was fit and normal probability plot was generated for the residuals from the fitted model³².

The generalized least squared approach was also adopted with production as a dependent variable among the lagged explanatory variables, such as consumed asbestos tones, labor and technical input. However, we adopted the exceptions to use consumption variable for estimation, while the rest of variables were estimated to a constant (zero), '*ceteris paribus*' because there were no complete data. This may seem strange, however as asbestos items are produced illegally to avoid detection, the producers are assumed to manufacture amounts that can be consumed completely. Indeed, this relates to the generalized definition of a production function, as the specification of minimum input requirements needed to produce designated quantities of output.

Production Model Framework

The concept of production frontier was the most appropriate approach to model production, with

given cross-section of asbestos producers in various countries³³. We assumed that the number of asbestos producers manufactured a homogeneous product using the same technology and same inputs. However, producers were likely to end up with different levels of output³⁴⁻³⁵. This variation in productivity would arise for a variety of reasons, partly due to the regulatory environment in which production takes place, including the differences in quality of inputs, the managerial and environmental factors.

We acknowledge that there is a 'potential' level of maximum output that can be achieved from a given technology with the given levels of inputs, and individual producing countries may be able to achieve only a fraction of this potential for a variety of reasons. Indeed, the assumption that all producers use the same technology and same inputs may not hold true in practice. Thus, the realized output levels across the selected production units in applied empirical approaches suggest that 'potential' maximum is obtained as an envelope. The 'average' output that can be realized from the given levels of inputs and technology takes the standard production function approach. The average output is thus presumed in the variations of performance across producers.

Policies, on the other hand play an important role in influencing variations in production performances³⁶. For example, the costs of operation may be influenced by country's legislations and is reflected in levels of infrastructure; leading to variations in output for the same level of measured inputs and may not be included explicitly as inputs. However, given sufficiently detailed input-output data, it is possible to estimate global-specific production functions in production function approach. Otherwise, an alternative is to use country-level data on input and output for estimating a production function approach and associated worldwide-level production functions.

The basic framework for estimating a specification for the asbestos production function is the following production function approach:

$$\ln Q_i = a_0 + a_1 \ln X_{i1} + a_2 \ln X_{i2} + \mu_i \quad (1)$$

where:

Q_i = asbestos output for the i -th producer,
 X_{ji} = level of j th asbestos input for the i th producer, a_{ij} = parameters of the production relationship relating j -th input to output for the i -th producer, and μ_i = random error term.

The coefficients a_{ji} are assumed to be random with

$$a_{ji} = \bar{a}_{ji} + v_{ji} \quad (2)$$

where v_{ji} is distributed with mean zero and a constant variance; $\bar{a}_{ji}$ is the constant reflecting the average response of output for variations in the level of j -th input. The random error v_{ji} is associated with the intercept term and combined with the error term μ_i in (1), i.e. substituting (2) into (1) we get

$$\ln Q_i = \bar{a}_0 + \bar{a}_1 \ln X_{i1} + \bar{a}_2 \ln X_{i2} + w_i \quad \text{and} \\ w_i = (\mu_i + v_{0i} + v_{1i} \ln X_{i1} + v_{2i} \ln X_{i2}), \text{ where } E(w_i) = 0 \text{ as well as, } \text{Var}(w_i) = \sigma^2 + \sum_{j=1}^2 \sigma_j^2 (\ln X_{ij})^2, \\ \text{Cov}(w_i, w_{i'}) = 0 \text{ for } i \neq i' \quad (3)$$

$$\sigma_j^2 = \text{var}(a_{ji}) \quad (4)$$

But in matrix form,

$$Y = XB + w$$

where

$$E(w) = 0, \text{ and } E(ww') = \Omega \quad (6)$$

Consider Y as a vector of output levels for n asbestos producers, X is a matrix of k inputs, i.e. including a column of ones, for n producers, B is a vector of k coefficients of production relationship, w is a vector of composite error terms, i.e. $w_i = (\mu_i + v_{0i} + v_{1i} \ln X_{i1} + v_{2i} \ln X_{i2})$ and Ω is a $(n \times n)$ non-singular positive definite matrix.

$$\Omega = \text{diag}(x_1' A x_1, x_2' A x_2, \dots, x_k' A x_k) \quad (7)$$

where

$$A = E\{(a_{ij} - \bar{a}_{ji})(a_{ij} - \bar{a}_{ji})'\} \quad (8)$$

The vectors x_j have $(n \times 1)$ dimension. The linear models with heteroskedastic error term can be interpreted using the statistical model in equations 3 to 6. Adopting from literature [34;37;38], we show that along with $\bar{a}_{ji}$, estimates of v_{ji} i.e. in the case of v_{0i} it is actually $v_{0i} + \mu_i$, can also be uncovered in this modelling. Thus, we have estimates of a_{ji} , providing a producer-specific production function,

$$\ln Y_i = a_0' + a_1 \ln X_{i1} + a_2 \ln X_{i2} \quad (9)$$

the estimated production function coefficients are a_j'

The production frontier is defined as

$$\ln Y^* = a_0^* + a_1^* \ln X_1 + a_2^* \ln X_2 \quad (10)$$

Where,

Y^* = output from the production frontier, A_j^* = coefficients of the production frontier such that $A_j^* = \max \{a_{ij} \mid i = 1, 2, \dots, n \text{ producers}\}$ by ignoring the discussion on distinguishing the intercept term in the original production function and the term when the function is transformed into the double-log form. And, given that the overall efficiency (IE) is defined as the ratio of actual output of producer

to the output level from the frontier function [34] proved in equation (10),

$$U_i = (Y_i / Y^*) \quad (11)$$

where ($U_i < 1$) due to the stochastic nature of the frontier, there is no restriction: but with $\tilde{Y}_i$ obtained as the predicted value of output from the production function for producer i , $U_i = (\tilde{Y}_i / Y^*)$, then ($1 > U_i > 0$). Technical efficiency (U_i) with respect to x_j implies $\tilde{Y}_{ij} = (a_{ji} / a_j^*)$ for $j = 1, 2, \dots$ and general efficiency (H); $H_i = (a_{0i} / a_0^*)$. Thus, output growth decomposition due to input growth, change in technical efficiency, and technical progress [26; 27]. The time-series data on output and inputs on a cross-section of producers is used where;

The production function is expressed for the panel data as

$$\ln Y_{ijt} = a_{0ijt} + a_{1ijt} \ln X_{1ijt} + a_{2ijt} \ln X_{2ijt} + \mu_i \quad (12)$$

and

$$a_{kijt} = (\bar{a}_{kjt} + v_{ikjt}) \quad (13)$$

there is now a production function corresponding to each producer 'i' for each period 't'; the production frontier can be defined for each period such that,

$$\ln Y_t^* = a_{0t}^* + a_{1t}^* \ln X_{1t} + a_{2t}^* \ln X_{2t} \quad (14)$$

where

$$a_{jt}^* = \max \{a_{jit} \mid i = 1, 2, \dots, n \text{ and } t = 1, 2, \dots, t\} \quad (15)$$

Production Model Validation

The descriptive statistics and correlation coefficients were computed in the analysis. The mean total asbestos production for the last 103 years since 1900 for all the countries is 1,736,658.5 Mt (cumulative is 180,992,485 Mt), while mean consumption is 266,417.196 Mt

(cumulative is 44,857,813 Mt)³⁰. The correlation between production and consumption of asbestos was significant ($0.000 < 0.005$). To this end, researchers were 95 percent confident that for consumers, consumption leads to an increase in production between 1 2,280 Mt to 3 3,890 Mt.

The asbestos equation is therefore:

$$\text{Total production in metric tons} = 1,051,713.8 + 2.309 \ln (\text{consumption tons}).$$

And, assuming an initial production, the hypothetical consumption rate could be placed at 2,000 MMt (million metric tons), the predicted amount of production would be 1,065,834 Mt. This is the tonnage of asbestos that we would suggest to be banned in our investigation. To check whether the data comprises the prediction in consumption, we used a normal P-P plot of regression-standardized residual. The points on the plot formed an almost linear pattern, indicating that normal distribution was a good model for this data set (see Figure 1).

Cost Analysis of ARDs

Costing information for treatment of ARDs (mesothelioma, asbestosis and lung cancer) were obtained from UKMMC (Universiti Kebangsaan Malaysia Medical Centre), which is 900 beds teaching hospital, owned by Malaysian Ministry of Higher Education. This is the first hospital in Malaysia that has implemented casemix system; also known as Malaysia-Diagnosis Related Group or MY-DRG³⁹⁻⁴⁰. The casemix system has been used as a management tool for enhancing quality and efficiency of UKMMC services since 2002⁴¹. The hospital publishes annual casemix report regularly, listing detailed unit cost for medical and surgical procedures as well as cost per episode of care classified into MY-DRG casemix system⁴².

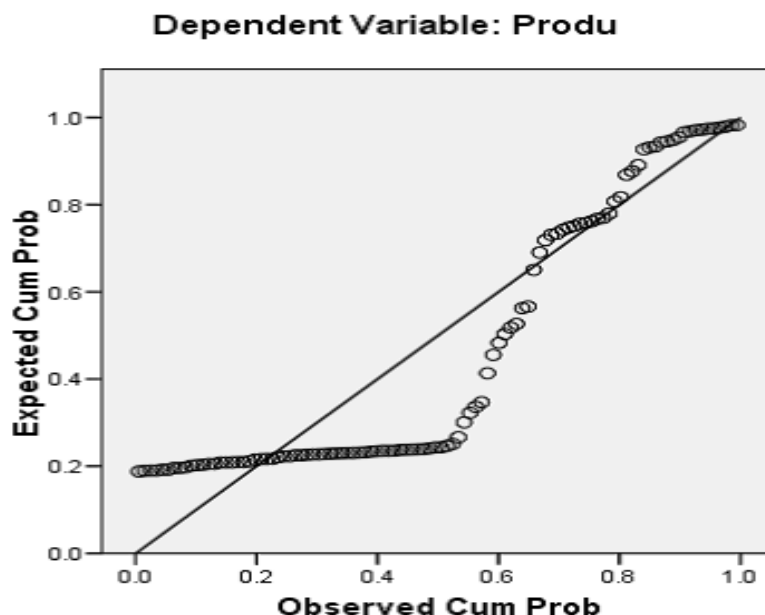


Figure 1: P-P plot of regression standardized residual with linear pattern.

For the cost burden analysis, researchers considered the economic burden of asbestos as a result of mining or producing it, that would lead to incurring costs and diseases, such as mesothelioma or chronic lung fibrosis. The health care costs incurred in turn depend on various factors which determine the intensity of burden, such as treatment modality, patient's age, duration of hospitalization and illness and co-morbidity; contributing to the health and economic burden of producing and consuming asbestos products. The cost burden incurred is borne by both the patients and health care services provider in terms of medical investigations, work opportunity costs, medications and treatments costs. The costs are incurred by individuals at the household level as patient costs and are paid by the government as the main health care provider from the public money. The economic burden in specialist clinics and hospitals partly includes personnel costs, medicines, procedures and administrative costs.

The burden borne by patients, their families or friends can be subdivided into direct and indirect costs. The direct costs comprise out-of-pocket

expenses or disposable income spent on travel and clinic fees when patients seek primary and secondary care and are paid at public or private health facilities. Whereas indirect costs include the work opportunity cost, i.e. income lost because of absence from work or time spent in hospitals instead of leisure⁴³.

The calculation of cost burden is as follows:

Cost of chemotherapy = Number of patients x Cost of chemotherapy per patient;

Cost of legal claims due to health effects = Number of patients x Average claim per patient;

Cost of stay in surgery ward = Number of days spent in hospital x Cost of admission per day;

Cost of pneumonectomy = Number of mesothelioma patients x Cost of surgery;

Cost of chronic lung fibrosis/ asbestosis = Number of asbestosis patients x Cost of treatment for asbestosis.

The conceptualized structural flow of asbestos economic burden is shown in Figure 2.

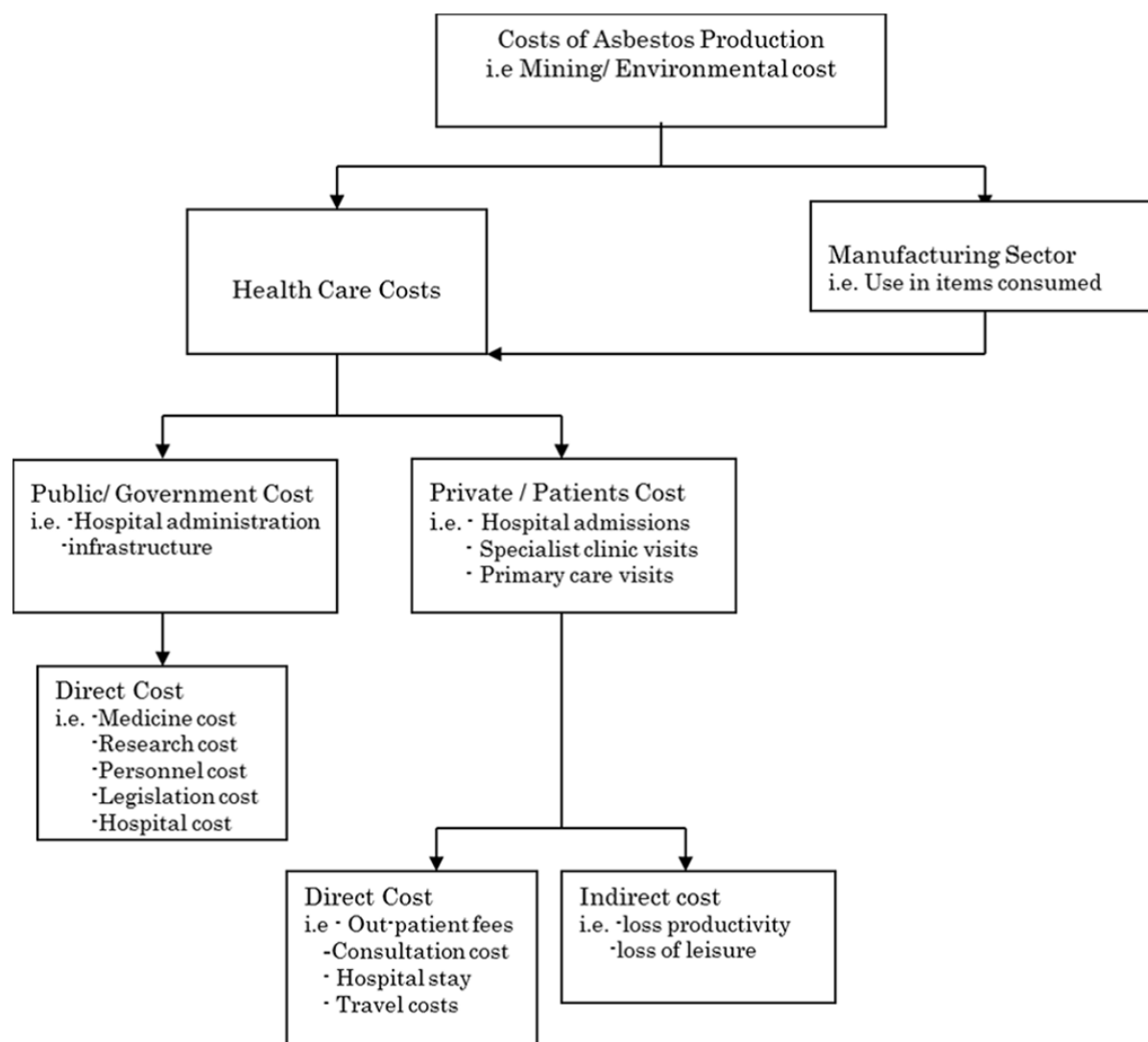


Figure 2: The conceptualized structural flow of asbestos cost burden

In the conceptualized structural flow the cost of mining asbestos includes manufacturing and consumption of asbestos items, which results in health care costs. The health care costs can be either patient or public expenses. Patient costs include hospital admission cost, specialist and primary care clinic visits cost, while public costs are expenses made on hospital administration and infrastructure. The economic burden is ultimately borne as a direct cost, such as out-patient fees, health consultation expenses, hospital stay cost and travel cost, whereas indirect cost can be loss

of productivity due to absence from work and time spent in hospital instead of leisure.

RESULTS

Cost of Consumption

The annual global asbestos consumption was estimated at 2.11 million metric tons and the per ton price for all grades of asbestos was around USD 1,260^{11, 30}. The approximate annual compensation amount for ARDs cases was also calculated in the analysis. The estimated workers' compensation was adopted from Manville Personal Injury Settlement Trust⁴⁴ and was equivalent to USD 4.28 billion (Table 1).

Table 1: Annual Cost of Asbestos Consumption and Health Claims

Source	Description	Amount in USD
Virta [11; 30]	Value of 2.11 MMt of asbestos at 1,260 USD per ton consumed in 2003	2.93 billion
WHO [20]; White [40]	Annual compensation for 107,000 ARD cases at 40,000.00 USD per claim	4.28 billion
Total		7.21 billion

Notes: MMt implies Million Metric Tons, USD implies United States Dollars, WHO implies World Health Organization, ARD implies Asbestos Related Diseases

Burden of ARDs Treatment

There are several methods of treatment for ARDs and the cost of treatment depends on diagnosis. In this study, the cost to treat 43,000 patients of mesothelioma by pneumonectomy i.e. surgery, was

estimated at USD 120 million^{2, 42}. The annual global cost of chemotherapy i.e. treatment with anti-cancer medicines at rate of USD 54,380.00 per case was about USD 2.33 billion^{2, 45} (Table 2).

Table 2: Estimated Cost of Treatment for Asbestos Related Diseases

Source	Type of disease	Treatment modality	Cost per case in USD	Number of patients	Annual cost in USD
Driscol [2]; HUKM [41]	Mesothelioma	Pneumonectomy/Surgery	2,803.36	43,000	120.00 million
Driscol [2]; Asukai [42		Chemotherapy/Medication	54,380.00	43,000	2.33 billion
Driscol [2]; HUKM [41]		Radiotherapy	4,569.64	43,000	196.50 million
Driscol [2]; HUKM [41]	Asbestosis	Medical	1,584.62	26,650	42.23million
Driscol [2]; HUKM [41]	Lung Cancer	Pneumonectomy/Surgery	2,803.36	26,650	74.70 million
Driscol [2]; Asukai [42		Chemotherapy/Medication	54,380.00	26,650	1.449 billion
Driscol [2]; HUKM [41]		Radiotherapy	4,569.94	26,650	121.78 million
Total Cost					4.34 billion

Notes: HUKM implies Hospital University Kebangsaan Malaysia, USD implies United States Dollar

Loss of Workdays

The loss of workdays by ARD cases is a public health concern. The annual loss of earnings for a case of lung cancer and asbestosis, including the visits to primary care clinic is about USD 13,320.37. The annual global loss of earnings for cases of asbestosis is USD 9.33 million^{42, 46} (Table 3).

Cost of Compensation

The individuals' exposure to asbestos and failure of product manufacturers to protect workers has led to one of the longest-running asbestos litigation problems⁴⁷. Table 4, presents the annual cost of asbestos consumed, cost of compensation and treatment for ARDs and loss of earnings. The annual global burden of asbestos use and ARDs is estimated at USD 11.92 billion.

Table 3: Loss of Earning due to Hospital Visits and Admissions in Asbestos Related Diseases*

Description	Type of Disease	Amount USD
Annual loss of earning due to visits to primary care clinic per case	Lung cancer	9,063.04
Annual loss of earning due to visits to primary care clinic per case	Asbestosis	3,122.58
Annual loss of earning due to visits to primary care clinic by 26,650 cases	Lung cancer	241.53 mil
Annual loss of earning due to visits to primary care clinic by 26,650 cases	Asbestosis	83.21 mil
Annual loss of earning due to hospital stay by 43,000 cases at rate of 399.84 USD each	Mesothelioma	17.19 mil
Annual loss of earning due to hospital stay by 26,650 cases at rate of 350.33 USD each	Asbestosis	9.33 mil
Annual loss of earning due to stay in medical ward by 26,650 cases at rate of 384.60 USD each	Lung cancer	10.24 mil
Annual loss of earning due to stay in surgical ward by 26,650 cases at rate of 399.84 USD each	Lung cancer	10.65 mil
Total		372.15 mil

Note: USD implies United States Dollar, HUKM implies Hospital University Kebangsaan Malaysia, WB implies World Bank. Malaysian per capita GNI in USD is 7,590 in 2009. GNI per day is a fraction of per capita GNI to annual days which is USD 20.79.

Source: HUKM [41], WB [43]

It can be seen that for every USD of asbestos consumed (Table 4), the global economy has to pay USD 1.46 for annual compensation and USD 1.61 for cost of treatment of ARDs and loss of earnings due to these conditions. In total for every USD of asbestos consumed, global economy loses USD 4.07 due to health consequences.

DISCUSSION

The purpose of this study is to make a contribution to literature to ban asbestos due to associated health and economic burden, by examining production function frontier-based estimate for asbestos products, including analysis of costs involved. We find that measures aimed at stopping consumption of asbestos goods per se are important in reducing health and economic burden. For instance, if countries ban the use of asbestos they could eliminate the costs incurred, particularly in Asia where most of asbestos is consumed. This is consistent with other studies,

which indicate increasing asbestos use in Asia [18; 20; 30]. The consumption of asbestos products impacts household members' welfare and development, family income savings as well as national resources due to expenditure on medications. In addition, asbestos causes health and economic burden to households, which are associated with death, psychological and mental trauma^{18, 48}.

With regard to production, the major producers were Russia followed by China, Brazil and Kazakhstan; these four countries produced almost 99 percent of world asbestos⁴⁹. There was about nine asbestos-producing companies operating in these countries except China, where the number of small-scale asbestos producers was not available⁵⁰⁻⁵¹. The health and economic burden caused by asbestos have persisted steadily though global production declined between 2011 and 2012, from 2.05 to 2.01MMt, which attributed to decrease in China's participation (Table 5)^{18, 49}.

However, cases of mesothelioma and lung cancers remain life-threatening and show inequalities in distribution of cost burden. The liability claims which asbestos-producing companies paid to settle health-related complaints by 2002 were about USD

21.6 billion. Unfortunately, only 37 percent of the amount was received after paying out expected expenses, which reveal the extent of economic burden borne by victims in addition to loss of life^{18, 44}.

Table 4: Global Burden of Asbestos Use and Asbestos Related Diseases

Source	Description	Amount USD
Virta [11]	Value of 2.11 MMt of Asbestos consumed in 2003	2.93 billion
Driscoll [2]; White [40]	Annual compensation for ARDs cases	4.28 billion
Driscoll [2]; HUKM [41]	Annual cost of treatment for ARDs	4.34billion
HUKM [41]; WB [43]	Annual loss of earning due to hosp visits & admissions for ARDs	372.15 million
Total cost		11.92 billion

Notes: HUKM implies Hospital University Kebangsaan Malaysia, WB implies World Bank, USD implies United States Dollar, MMt implies Million Metric Tons, ARDs implies Asbestos Related Diseases

In the investigation, we found that asbestos is used due to low cost involved in production of materials, particularly in developing world. Some of these items include asbestos-cement products, car brakes and heat-resistant surfaces. Asbestos-cement products accounted for 85 percent and brake linings for 10 percent of world asbestos sales^{49, 50}. But many developed countries which previously used asbestos products are affected by the related epidemic^{18, 20, 50}. According to World Health Organization, mortality from, mesothelioma was about 92,253 deaths across 83 countries between 1994 and 2008⁵². World Health Assembly adopted resolution (58-22) to reduce mortality rates and chemical exposures in workplace but not much improvement has been achieved, despite the huge expenditure⁵³. In this research, we support efforts to stop all asbestos use and production as found in other studies³⁰, to

reduce health and economic burden resulting from its global use.

Employment in asbestos mines and mills is difficult to assess. During 1976 about 265 workers were employed in USA, in 2003 the global estimated number was 7,200, while total employment including underground mining was around 8,000 to 10,000 persons. Asbestos employment in USA plants was about 13,900, which dropped to 418 in 1997⁵⁴⁻⁵⁶. The finding relates to other studies which suggest that annual deaths due to occupational asbestos exposure are expected to exceed 90,000 persons after a latency period^{2, 18}, though the suggested permissible exposure limit for asbestos at workplace is 0.1 fibers/cc of air^{57, 58}. The study emphasises early detection and efficient management of asbestos-generated impacts by controlling and reducing them with intention to stop asbestos production and consumption, and ensuring reduced health and economic burden.

Table 5: World Asbestos Production by Country 1, 2: 2009 - 2013 [Metric Tons]

Country ³	2009	2010	2011	2012	2013
Argentina	322	341	105	100e	100e
Brazil	288,452	302,257	306,321	304,569r	307,000
Canada ⁴	150,000	100,000	50,000	-----	----
China ⁴	440,000	400,000	440,000	420,000	420,000
India ⁴	2614	2544	250	245	240
Kazakhstan	230,000	214,100	223,100	241,200	242,000
Russia ⁴	1,000,000e	995,174r	1,031,880r	1,041,000r	1,050,000
Zimbabwe	4,971	2,400	----	----	----
	2,110,000	2,010,000r	2,050,000r	2,010,000r	2,020,000

Estimated, Revised

1World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

2 Marketable fiber production. Table includes data available through May 2, 2014.

3 In addition to the countries listed. Afghanistan, North Korea, Romania and Slovakia also produced asbestos, but output was not officially reported, and available general information was inadequate for the formulation of reliable estimates of output levels.

4 Reported figure.

Another approach to control the use of asbestos is to focus on developing asbestos substitutes. The key factors in developing substitutes were the cost of the substitute (15-20% higher), extra manufacturing, and product design cost and also performance cost⁵⁹⁻⁶⁰. In U.S. substitutes have almost taken over asbestos market. In Europe and some other developed countries, the ban has ensured that no asbestos will be consumed after 2005. The list of materials which are substituted for asbestos include fibers of aramid, cellulose, and ceramic, as well as fiber glass, flakes and fibers of graphite, mica, fibers of polyethylene, polypropylene, polytetrafluoroethylene and steel, and also wollastonite^{59, 61-64}.

The strength of this study lies in application of strategic approach of production frontier, which is most appropriate for modeling production, given the cross-section of asbestos hazards predicted worldwide^{2, 3, 18, 20}. In addition, we used a review of scientific literature and cost analysis from public database studies. The study has several limitations including biases created by hypothetical assumptions adopted in development of production frontier, such as the number of asbestos producers manufactured a homogeneous product using the same technology and same inputs. The estimated production function may seem to have a limited value with consumption as an independent variable. There was inadequate literature on asbestos economic burden, such as the number of workers in underground mines and cost in terms of time spent by care givers. Thus, our finding should be viewed as a basis for further investigations to ban all forms of asbestos.

Malaysia is not an asbestos producing country, and no official data is available on asbestos import,

consumption and ARDs in Malaysia. However, it is producing various asbestos containing materials, such as asbestos cement, asbestos pipes and automobiles brake pads with asbestos lining; which can lead to asbestos exposure and ARDs, especially among workers who work in such industries. Keeping the Malaysian situation in mind, researchers assumed that there might be some potential cases of ARDs, which go un-noticed by physicians due to their lack of knowledge. The reason for using Malaysia for calculating cost of ARDs treatment was the researchers' access to the case mix database of UKMMC. As mentioned earlier that asbestos related data is kept confidential and is very hard to access, especially in developing countries. Therefore, for their study the researchers utilized whatever related information they could access from various documents, studies and countries. So the access to asbestos related data was one of the limitations of researchers. There is also no available data about number of global ARDs cases that is why researchers used the estimated figures and extrapolated the results. It is suggested that a more detailed study may be conducted in future, after a reliable official data has been gathered and made available at any point of time to estimate the accurate cost burden.

CONCLUSION

We examined the health and economic burden of asbestos through development of macro-global consumption-production model, using production function frontier-based estimate for asbestos products and its related costs. The investigation revealed consumption as the key variable in decisions to eliminate asbestos hazards and found that global economic burden of asbestos has an

estimated cost of USD 11.92 billion. Out of this, USD 4.34 billion is the healthcare cost of managing ARDs and USD 4.28 billion is the cost of compensation for ARDs. From the remaining USD 3.3 billion, USD 2.93 billion is the value of asbestos consumed in 2003 and USD 372.15 million is the loss of earning due to hospital visits and admissions. For every USD spent on consumption of asbestos, global economy has to absorb USD 4 due to health consequences of ARDs. Asbestos use causes diseases such as mesothelioma and cancers, which impact household welfare, economic development and reduces savings due to medication expenses and related deaths. Indeed, the health and economic burden caused by asbestos cannot be justified by motives of reducing poverty or improving economic wellbeing in developing countries.

We promote global collaboration to ban asbestos production and use, and support efforts to stop asbestos production and consumption within next decade. The information generated from this study is expected to convince decision makers to ban asbestos in the developing countries and globally.

Abbreviations

ARDs: Asbestos Related Diseases

ESH: Engineering Statistic Hand.GNI: Gross National Income

ID: International Dollars

Mt: Metric Tons

MMT: Million Metric Tons

MY-DRG: Malaysia - Diagnosis Related Group

RM: Ringgit Malaysia

UKMMC: University Kebangsaan Malaysia Medical Centre

USA: United States of America

USD: United States Dollars

USGS: United States Geographical Survey

WB: World Bank

WHO: World Health Organization

Take Home Messages

- Asbestos is still widely used, especially in developing countries despite of its known danger.
- Asbestosis, mesothelioma and lung cancer are three common diseases related asbestos exposure.
- Annual total economic burden of asbestos globally is estimated to be in USD 11.92 billion.
- For every 1 dollar spent on consumption of asbestos, global economy has to absorb almost 4 dollars due to health consequences of ARDs.

- Banning of asbestos production and usage in production of goods has far-reaching impacts on household welfare, health and economic development.

Authors' contributions

“SA conceived the study, participated in its design, coordination, and carried out costing analysis and has also drafted the manuscript. AMQ helped to design the study, obtained clinical costing data and has written - refined the manuscript. DB participated in the design of study and performed the econometric and statistical analysis. All authors have read and approved the final manuscript.”

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Competing interests

The authors declare no competing interests.

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