4. Economic Cost/Burden Incurred by Asbestos Exposure and ARDs

4- A-B. Assessment of Asbestos Production and Consumption with Associated Health and Economic Burden

Syed Aljunid[1, 2], Ahmad Munir Qureshi[1], David Baguma[1], Isidore Koffi Kouadio[1],

1. United Nations University-International Institute for Global Health (UNU-IIGH)

UKM Medical Centre, Jalan Yaacob Latif, Bandar Tun Razak

56000 Kuala Lumpur, MALAYSIA

2. International Casemix and Clinical Coding Centre (ITCC-UKMMC)

University Kebangsaan Malaysia, UKM Medical Centre,

Bandar Tun Razak

56000 Kuala Lumpur, MALAYSIA

Corresponding Author: Syed Aljunid. E-mail: syed.aljunid@unu.edu

Abstract

The health and economic burden caused by asbestos cannot be justified by motives related either to reducing poverty or promoting economic development. In the paper we contribute to literature aimed at the need to ban asbestos use. The health and economic burden of asbestos is presented by the development of the macro-global consumption-production model, using the production function frontier-based estimate for asbestos products, and the cost tabulation. The generalized least squared approach was used in the analysis. Production of asbestos in metric tons (Mt) was adopted as a dependent variable among the explanatory variables, such as consumption in Mt. The findings reveal consumption as a key variable in the investigation. Additionally, the annual total economic burden of asbestos is estimated in United States dollars (USD) to be USD 11.75 billion. Out of this cost, USD 4.54 billion per annum is the economic burden of managing three most common asbestos-related diseases (ARDs) i.e. mesothelioma, asbestosis and lung cancer. The cost of compensation for patients suffering from ARDs is USD 4.28 billion. For every USD 1 spent on consumption

of asbestos, the global economy has to absorb USD 3 due to health consequences of ARDs. Indeed, the banning of asbestos production and usage in the production of goods has far-reaching impacts on household welfare, health and economic development. Expenses incurred on treatment of ARDs reduce family as well as national resource savings, and leads to deaths. The insights revealed are expected to inform decision makers the need to ban all forms of asbestos use, especially in developing countries where usage is increasing.

Keywords: asbestos**,** costs, mesothelioma; asbestosis, lung cancer, savings; welfare; developing countries.

1. Introduction

Asbestos is one of the most important occupational carcinogens responsible for causing nearly half of the deaths from occupational cancers [1; 2]. The historical and commercial use of asbestos is attributed to the extraordinary high tensile strength, flexibility, poor heat conduction and resistance to chemicals [3].

The diseases linked to asbestos, such as mesothelioma, fibrosis of the lung, pleural plaques and lungs, as well as laryngeal cancers, are caused by inhalation of asbestos fibres, primarily from contaminated air in the workplace, during indoor air activities or from buildings containing friable materials. Furthermore, asbestos-related diseases (ARDs) can be induced through drinking water, which may increase water management challenges [4; 5]. This can also occur during the installation, maintenance and use of asbestos-contained products, such as vehicles brakes and building tiles [7; 6]. In some instances, the risk of mesothelioma increases with exposure time period and requires urgent warning to prevent the explosion of ARDs [8; 9]. Also, exposure to asbestos is known to synergistically increase the risks of lung cancer among tobacco smokers [10]. Moreover, ARDs have high fatality rates, e.g., with a median survival of twelve months for mesothelioma following initial manifestation [6] and patients do not usually respond well to medical treatment [11].

The heavy burden of ARDs is partly attributed to rampant use of asbestos between the 1960s and 1970s in the western countries, even though many of them banned its use since the early 1990s [8]. Apparently, about 125 million people are exposed to asbestos at the workplace and 107,000 are dying every year [13]. Furthermore, the malignant types of ARDs are known to go through a long latency period, with 20-50 years from exposure to manifestation. For instance, the mortality rate for mesothelioma has been rising in developed countries in the past 20 years aftera sustained period of asbestos use. The burden of mesothelioma is also characterized by the short span of time that it takes for the victim to progress from manifestation to death. In the UK alone, 2,000 deaths from asbestos exposure were predicted between 2011 and 2015 and the cost of compensation was estimated to be 300 billion USD [8].

In terms of the concerted global efforts to ban asbestos, the European Union member states put emphasis on the need to end asbestos use, and the World Health Organization recommended the prohibition and ban of all forms of asbestos [8]. Yet chrysotile asbestos is widely used, with approximately 90 percent being utilized in asbestos-cement building materials, and trading tends to shift to low- and middle-income countries such as in Africa, Asia and Latin America [14].

The wide use of asbestos in low- and middle-income countries owing to its low cost, the false assurance provided by the absence of the disease burden within the latency period and weak surveillance system to detect ARDs [15], is based on misinformation and not cognizant of asbestos-related health risks which further exacerbates consequences [16]. Moreover, the miseries caused by ill health and death cannot be justified on the basis of the cheapness of asbestos inputs to improve incomes and reduce poverty [17]. Furthermore, there is the unresolved question as to who will be held responsible for the health hazards caused to public by the dangerous waste left behind after the mines are closed or after inappropriate disposal of depreciated items, which indicates that the asbestos burden could be perpetuated to future generations. Besides, are the countries ready to handle the related health and economic burdens created by asbestos, given the low economic growth among the countries in question. At the same time, asbestos-related disease epidemics observed in the high-income countries are likely to arise in the future among countries where asbestos continues to be widely used, especially in low- and middle-income countries.

In the context of the hazards created by asbestos, this paper presents the development of macro global consumption-production model, including production function frontier-based estimate for asbestos products, and cost analysis. And, guide decisions on the stopping of asbestos consumption and minimize the associated health and economic burden. We also intend to make a contribution to the needed to justify the banning of asbestos as such information is inadequate. The insights revealed could be used for decisions taken with regard to banning all forms of asbestos, especially in developing countries by public health workers, policy-makers, governments and leaders.

2. Materials and Methods

2.1 Modeling asbestos production

The data on asbestos were collected from secondary sources, including internet search of scientific data bases such as *Pubmed*, and United States Geographical Survey (USGS) documents [18] and used production and consumption data from 1900 to 2003. This was mainly because there is incomplete data on asbestos due to the confidentiality involved in use. We also assessed whether the data were normally distributed. To check the distribution of the data, the normal probability-plot technique was used [19]. The underlying assumptions for checking normality included the assumption that the data behaved as random drawings, from a fixed distribution, with a fixed location and a fixed scale. However, the researchers acknowledged the error component in most common statistical models was the specific assumption of the fixed location and a fixed scale; given that if one of the major assumptions of the model has been violated in the analysis, the residuals from the fitted model are not normally distributed. Otherwise, adopting from the Engineering Statistic Hand (ESH), a model is fit and a normal probability plot is generated for the residuals from the fitted model [20].

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 the consumption variable for estimation while the rest of the variables were estimated to a constant (zero)**,** *ceteris paribus,* because there were no complete data.

2.2 Production Model Framework

The concept of production frontier was the most appropriate approach to model production, given the cross-section of asbestos producers in various countries, as used in related literature [21]. We assumed that a number of asbestos producers manufactured a homogeneous product using the same technology and the same inputs. However, the producers were likely to end up with different levels of output [22; 23]. This variation in productivity would arise for a variety of reasons, partly due to the regulatory environment in which production takes place, including differences in the quality of inputs, managerial factors and environmental factors.

But we acknowledge that there is a ‘potential’ level of maximum output that can be achieved from a given technology with 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 the producers use the same technology and the same inputs may not hold strictly in practice. Thus, the realized output levels across selected production units, in applied empirical approaches suggest the 'potential' maximum is obtained as an envelope. The 'average' output that can be realized from the given levels of inputs and the technology take the standard production function approach. The average output is thus presumed in the variation of performance across producers.

Policies, on the other hand, play an important role in influencing variations in production performances [24]. For example, the costs of operation may be influenced by country legislations and 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 the production function approach. Otherwise, an alternative is to use country-level data on inputs 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:

$$LnQ_i = ao_i + a1_i LnX_i + a_{2i} LnX2_i + \mu_i \quad (1)$$

where:

Q_i = asbestos output for the i-th producer, Xj_i = level of jth asbestos input for the ith 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 aj_i are assumed to be random with

$$aj_i = \bar{a}j_i + vj_i \quad (2)$$

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

$LnQi = \bar{a}_o + \bar{a}_1 LnX1_i + \bar{a}_2 LnX2_i + w_i$ and $w_i = (\mu_i + v_{oi} + v_{1i} LnX1_i + v_{2i} LnX2_i)$, where $E(w_i) = 0$ as well as,

$$Var(w_i) = \sigma^2 + \sum_{j=1}^{2} \sigma_j (LnX)^2_{ij},\ Cov(w_i, w_i') = 0 \text{ for } i \neq i' \quad (3)$$

$$\sigma_j = var(a_j) \quad (4)$$

But in matrix form,

$$Y = XB + w \quad (5)$$

with

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

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. $w_i = (\mu_i + v_{oi} + v_{1i} LnX1_i + v_{2i} LnX2_i)$ and Ω is a (nxn) non-singular positive definite matrix.

$$\Omega = diag(x1'A\,x1, x2'A\,x2, \ldots. xk'A\,xk) \quad (7)$$

where

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

The vectors xj have (nx1) dimension. The linear models with heteroskedastic error term can be interpreted using the statistical model in equations 3 to 6. Adopting from literature [22;25;26;], we show that along with $\bar{a}j$, estimates of v_{ji} i.e. in the case of $v0_i$ it is actually $v0_i + \mu_i$, can also be uncovered in this modeling. Thus, we have estimates of a_{ji}, providing a producer-specific production function,

$$LnY_i = a0'_i + a1_i LnX1_i + a2'_i Lnx2_i \quad (9)$$

the estimated production function coefficients are aj'_i

The production frontier is defined as

$$LnY^* = a^*_o + a^*_1 LnX1 + a^*_2 LnX2 \quad (10)$$

where:

Y^*= output from the production frontier, A^*_j = coefficients of the production frontier such that $a^*_j = \max\{a_{ij}\ \phi\ i = 1, 2, ..., n \text{ producers}\}$ 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 (И) is defined as the ratio of actual output of producer to the output level from the frontier function [22] proved in equation (10),

$$И_i = (Yi /Y^*) \quad (11)$$

where ($И_i$ <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, $И_i = (\tilde{Y}_i /Y^*)$, then ($1 > И_i > 0$). Technical efficiency ($Й_i$) with respect to x_j implies $Й_{ij} = (a_{ji} /aj^*)$ for j = 1, 2,: and general efficiency (H); $H_i = (a0_i /a0^*)$. Thus, output growth decomposition due to input growth, change in technical efficiency, and technical progress [27; 28]. 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

$$LnY_{ijt} = a0_{ijt} + a1_{i1jt} LnX1_{ijt} + a2_{1jt} LnX2_{ijt} + \mu_i \quad (12)$$

and

$$ak_{ijt} = (\bar{a}k_{jt} + v_{ikjt}) \quad (13)$$

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,

$$Ln\ Y^*_t = a_{ot}^* + a1_t^* LnX1_t + a2^*_t LnX2_t \quad (14)$$

where

$$a_{jt}^* = \max \{aj_{it}\ \Phi\ i = 1, 2,\ldots n \text{ and } t = 1, 2,\ldots t\} \quad (15)$$

2. 3 Production Model validation

The descriptive statistics and correlation coefficients are computed in the analysis. The mean total asbestos production for the last 104 years since 1900 for all the countries is 1,736,658.5 Mt. and mean consumption is 266,417.196 Mt. The correlation between production and consumption of asbestos was found to be significant (0.000<0.005). To this end, the researchers are 95 percent confident that for consumers, consumption leads to an increase in production somewhere between 1, 2280 Mt to 3, 3890 Mt.

The asbestos equation is, therefore:

Total production in metric tons= 1,051,713.8 + 2.309In (consumption tons).

And, With a hypothetical consumption rate at 2,000 Mt of asbestos, the predicted amount anticipated in production would be equivalent to 1,065,834 Mt. This is the tonnage of asbestos that we could suggest to be should be banned in the investigation. To check whether the data would comprise the prediction in consumption, we used a normal P-P plot of regression standardized residual. The points on the plot formed nearly a linear pattern, which indicated that the normal distribution was a good model for this data set (see Figure 1).

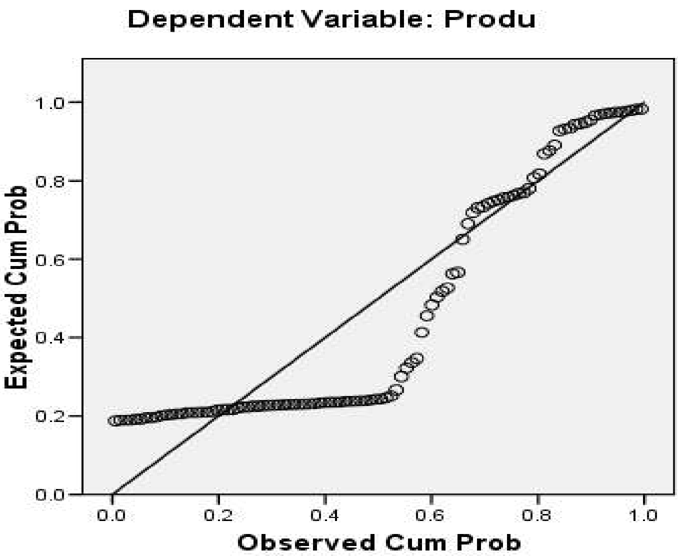

Figure 1: The graph of normal P-P plot of regression standardised residual showing a linear pattern of points indicating the data were good for the model

2.4 Cost Analysis of ARDs

In the study, to analyze the cost burden, researchers considered the economic burden of asbestosis as a result of mining or producing asbestos fibers, and 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 the burden. Factors such as treatment modalities, duration of hospitalization, age of patients, duration of illness and co-morbidity contribute to the health and economic burden of producing and consuming asbestos products. The burden of cost incurred is borne by both patients and providers of health care services in terms of medical investigations (tests), opportunity cost to work, medications and treatments. And the costs are incurred by the individuals at household level, as patient costs and are also paid by the government as the main health care provider, from public money. The economic burden in specialist clinics and hospitals partly includes personnel cost, medicine cost, procedure cost, and administrative cost.

The burden borne by patients and their families or friends, can be subdivided into direct and indirect costs. The direct costs such as out-of-pocket expenses or disposable income spent on travel and clinic fees when patients seek primary care and secondary care are paid in public or private health facilities. And the indirect costs include the opportunity cost to work i.e. the income lost because of absence from work or the time spent in hospitals instead of leisure [29].

The calculation of cost burden is provided as follows:

Cost of chemotherapy treatment = 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 Pnuemonectomy = 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 the asbestos economic burden is shown in Figure 2.

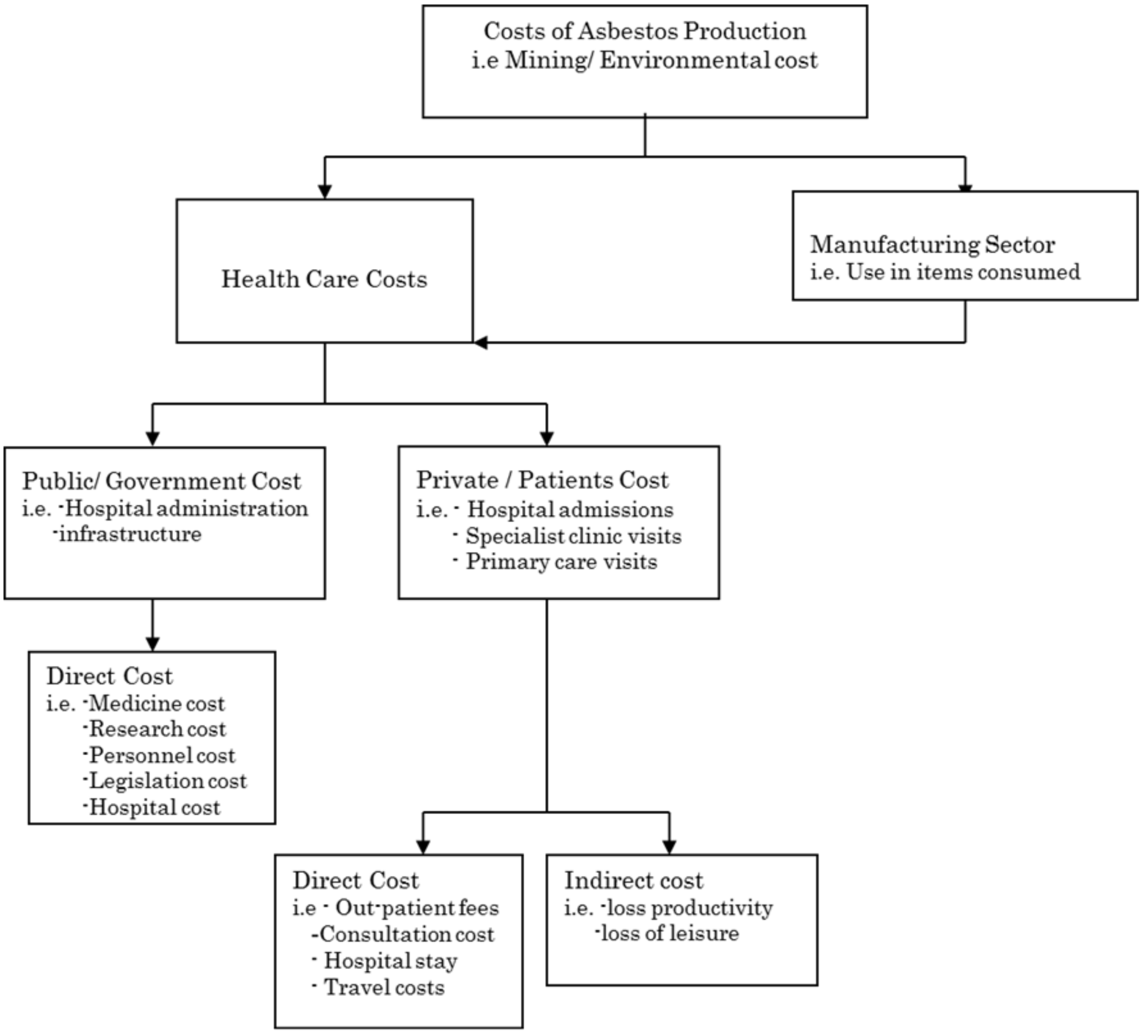

Figure 2: The conceptualized structural flow of the asbestos cost burden

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 cost include hospital admission cost, specialist clinic visit cost and primary care visit cost. While as, 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, while as indirect cost can be loss of productivity due to absence from work and time spent in hospital instead of important leisure.

Findings of Cost Analysis of ARDs

3.1 Cost of Consumption

To explore further insights on cost burden, annual global asbestos consumption from literature is estimated to be 2.11 million metric tons [18], and per ton price for all grades of asbestos is about USD 1,260 [18; 46].The approximate amount of annual compensation for cases of ARDs is also calculated in the analysis. The estimated worker's compensation is adopted from Manville Personal Injury Settlement Trust [34] and is equivalent to USD 4.28 billion (Table 1).

Table 1: Annual Cost of Asbestos Consumption and Health Claims

Source	Description	Amount in USD
Virta [18; 46]	Value of 2.11 MT of asbestos at 1,260.00 USD per ton consumed in 2003	2.93 billion
White [34]; WHO [47]	Annual compensation for 107,000 ARD cases at 40,000.00 USD per claim	4.28 billion
	Total	7.21 billion

Notes: MT implies metric tons, USD implies Unites States Dollars

3.2 Burden of treatment of ARDs

ARDs are treated in several ways and the cost of treatment depends on the diagnosis. In the study, for instance, the cost to treat 43,000 patients of mesothelioma by pneumo-nectomy i.e. surgery is estimated at 120 million USD [32; 34]. The annual global cost of chemotherapy i.e. treatment with anticancer medicines, at rate of 54,380.00 USD per case is approximated at USD 2.33 billion [40; 49] (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
HUKM [34]; WHO [40]	Mesothelioma	Pneumonectomy/surgery	2,803.36		120.00 million
Asukai et al., [32];		Chemotherapy medication	54,380.00	43,000	2.33 billion
WHO [40]		Radiotherapy	4,569.94	43,000	196.50 million
HUKM [34]; WHO [40]				43,000	
HUKM [34]	Asbestosis	Medical	1,584.62	26,650	42.23 million
HUKM [34]	Lung Cancer	Pneumonectomy/ Surgery	2,803.36	26,650	74.70 million
Asukai et al., [31]		Chemotherapy/Medication	54,380.00	26,650	1.449 billion
HUKM [34]		Radiotherapy	4,569.94	26,650	121.78 million
	Total Cost				4.34 billion

Notes: HUKM implies Hospital University Kebangsaan Malaysia, WHO implies World Health Organisation, USD implies United States Dollars, ARD implies Asbestos Related Diseases

3.3 Loss of workdays

The loss of workdays by ARD cases is an appalling public health concern [44]. The annual loss of earning for a case of lung cancer and asbestosis, including the number of visits to primary care clinics in the study is about USD 9,063.04. The global annual loss of earning for cases of asbestosis is USD 43.99 million [34; 50] (Table 3).

3.4 Cost of Compensation

Individuals' exposure to asbestos and failure of many product manufacturers to protect workers has been one of the longest-running litigation in the asbestos problems. Table 4, presents the annual costs of asbestos consumed, cost of compensation for ARDs, cost of treatment for ARDs,

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

Description	Type of Disease	Amount (USD)
Annual loss due to visits to primary care clinics in relationship to daily GNI per case	Lung Cancer	4,791
Annual loss due to visits to primary care clinics in relationship to daily GNI per case	COPD/Asbestosis	1,651
Annual loss of earning due to visits to Primary Care Clinic by 26,650 patients in relationship to daily GNI	Cancer lung	127.68 million
Annual loss of earning due to visits to Primary Care Clinic by 26,650 patients in relationship to daily GNI	Asbestosis	43.99 million
Annual loss of earning due to hospital stay for 43,000 patients at a rate of USD 399.84 each	Mesothelioma	9.09 million
Annual loss of earning due to hospital stay for 26,650 patients at a rate of USD 350.33 each	Asbestosis	4.94 million
Annual loss of earning due to stay in medical ward for 26,650 patients at a rate of USD 384.60 each	Lung cancer	5.42 million
Annual loss of earning due to stay in surgery ward for 26,650 patients at a rate of USD 399.84 each	Lung cancer	5.63 million
	Total	196.75 million

Notes: *Malaysian per capita GNI in USD is 6,764 in 2009. The GNI per day is a fraction of the per capita GNI to annual days, which is USD 20.13 Source: HUKM [35]; World Bank [50]

and loss of earning. The annual global burden of asbestos use and ARDs is estimated at USD 11.75 billion.

It can be seen from Table 4 that for every 1 USD of asbestos consumed, the global economy has to pay USD 1.46 for annual compensation and USD 1.55 for cost of treatment of ARDS and loss of earnings due to these conditions. In total for every I USD of asbestos consumed, the global economy loss by USD 3.01 due to health consequences.

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

Source	Description	Amount (USD)
Virta [18; 46]	Value of 2.11 Mt. of asbestos consumed in 2003	2.93 billion
White [34]; WHO [47]	Annual compensation for ARDs patients	4.28 billion
Asukai et al., [32]; HUKM [34]; WHO [47]	Annual cost of treatment for ARDs	4.34 billion
HUKM [34]; WHO [47]; World Bank [52]	Annual loss of earning due to hospital visits and admissions for ARDs	196.75 million
	Total Cost	11.75 billion

Notes: HUKM implies Hospital University Kebangsaan Malaysia, WHO implies World Health Organisation, USD implies United States Dollars, ARD implies Asbestos Related Diseases

4. Discussion

The purpose of the study is to make a contribution to literature on the need to ban asbestos due to health and economic burden, by examining production function frontier-based estimate for asbestos products including an analysis of the costs involved. In the study, we find that measures aimed at stopping the consumption of asbestos goods per se are important in reducing health effects and economic burden. For instance, if the countries ban the use of asbestos [29; 30], they could eliminate the costs incurred, particularly on the Asian continent where the majorityof asbestos is consumed. This finding is consistent with other studies which indicate increasing asbestos use on the Asian continent [31].The consumption of asbestos products has far-reaching impacts on household members' welfare and development. Family income savings as well as national resources are drained due to expenditure on medications. In addition, asbestos leads to severe effects, like death, psychological or mental trauma to households, and the associated health and economic burdens.

With regard to production, the leading producers are Russia, followed by China, Brazil, Kazakhstan, Canada, and Zimbabwe. These six countries produce about 96percent of world asbestos. We also found that there are more than 30 asbestos-producing companies, operating worldwide, excluding China, where the number of small-scale asbestos producers is not accurately available [32]. The health and economic burdens caused by asbestos production, however, have persisted steadily in the world, although the global production between 2007 and 2008 shows a decline from 2.30 to 2.09 Mt, attributed to the decrease in China's participation (Table 5). And, the cases of mesothelioma and lung cancer remain life-threatening and show unnecessary inequalities in the distribution of the cost burden. For instance, asbestos liability claims, which asbestos-producing companies paid by 2002, were about $21.6 billion, to settle health-related complaints. Unfortunately, only 37percent of expenditures is received after paying out the expected expenses [34], which reveal partly the extent and incidence of the economic burden borne by the victims in addition to loss of life.

In the investigation we found that asbestos is used due to the low costs involved in production of products, particularly in the developing world. For example, some of these low cost items include asbestos-cement products, car brakes and heat-resistant surfaces. Asbestos-cement products previously accounted for about 85percent, while brake linings accounted for 10percent of world asbestos sales [36; 34]. Unfortunately, many developed countries which previously used asbestos products are seriously affected by related epidemics [39]. For instance, according to the mortality database maintained by World Health Organization (WHO), mesothelioma contributes 46,476 deaths in 62 countries between 1994 and 2004 [38]. At the same time, the five-year Cancer Strategy Reform (2000-2005) and World Health Assembly Resolution -58.22, intentions to reduce mortality rates and chemical exposures in the workplace has not resulted in much improvement, even after huge expenditures [39; 40]. In this study, therefore, we suggest the need to stop all asbestos use and production as found by other studies [18] in the effort to reduce health and economic burdens resulting from its global use.

Table 5: World Asbestos Production by Country [1,2]; 2004-2008 [in Metric Tons]

Country[3]	2004	2005	2006	2007	2008
Argentina	267	260	299	282;r	280;[e]
Brazil, fiber	252,067	236,047	227,304	252,204	255,000;[p]
Bulgaria; [e]	300	300	300	300	----
Canada	220,000	200,000;[r,e]	200,000;[r,e]	180,000;[r]	180,000;[e]
China;[e]	400,000	400,000	360,000	390,000;[r]	280,000
Columbia, crude ore; [e]	60,000	60,000	60,000	60,000	60,000
India; [e]	18,000	19,000	20,000	21,000	20,000
Iran; [e]	6,000; [4]	1,300	1,300;[r]	1,400	1,400
Kazakhstan	346,500	305,500;[r]	314,700;[r]	292,600[;r]	230,100
Russia; [e]	923,000[; 4]	925,000	925,000	1,025,000;[r,4]	1,017,000;[4]
Serbia	7,300[; r,5]	4,080;[r,5]	4,500; [r]	---- [r]	----
Zimbabwe	104,000	122,041	100,000;[e]	80,000;[r,e]	50,000;[e]
Total	2,340,000[;r]	2,270,000;[r]	2,210,000;[r]	2,300,000;[r]	2,090,000

Notes: [e]Estimated. [p]Preliminary. [r]Revised. --Zero.

[1]World totals, US. data, 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 April 23, 2009.

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

[4]Reported figure.

[5]Montenegro and Serbia formally declared independence in June 2006 from each other and dissolved their union.

Source: Virta [50]

Employment in asbestos mines and mills is difficult to assess but some data is emerging slowly. In the study we find that and during 1976 employment mines and mills was substantial, and workers were employed in open-pit mining [41]. And, owing to many small underground mining operations, an estimated 8,000 to 10,000 persons had worked in asbestos mines and mills worldwide. This finding, however, relates to others studies which suggest that annual deaths due to occupational asbestos exposure are expected to exceed 9,000 after latency period [42; 44]. Though permissible exposure limit for asbestos at the workplace is estimated at 0.1 fibers/cc of air [43], the study encourages early detection and efficient management of asbestos- generated impacts by controlling and reducing them with the intention to stop asbestos production and consumption, as well as ensuring reduced health and economic burdens.

The strength of the study is the application of the strategic approach of production frontier, which was most appropriate for modeling production, given the cross-section of asbestos hazards predicted in countries worldwide [44]. In addition, we used a comprehensive review of scientific literature and cost analysis, based on data in public databases, which is widely referenced in studies. The study had several limitations including the biases created by hypothetical assumptions adopted in development of the production frontier such as, the assumption that the number of asbestos producers manufactured a homogeneous product use the same technology and the same inputs. In addition there was inadequacy of literature on economic burden such as the number of workers in underground mines or cost in terms of time spent by care givers, as compared to epidemiological publications. Thus our finding should be viewed as a basis for further investigation on the need to ban all form of asbestos.

5. Conclusion

The study examined health and economic burden of asbestos through the development of the macro-global consumption-production model, and using production function frontier-based estimate for asbestos products and its related costs. The investigation reveals consumption as a key variable in the decisions to eliminate asbestos hazards. And the finding that global economic burden of asbestos has an estimated cost of USD 11.75 billion. Out of this, the total of USD 4.54 billion is the healthcare cost of managing ARDs, and another USD 4.28 billion is the cost of compensation for patients suffering from ARD. For every USD 1 spent on consumption of asbestos, the global economy has to absorb USD 3 due to health consequences of ARDs. Furthermore, use of asbestos causes diseases such as mesothelioma and cancers, which impact household welfare and economic development, as well as reduces savings due to medication expenses and related deaths. Indeed, health and economic burdens caused by asbestos cannot be justified by motives related to either reducing poverty or improving economic wellbeing in developing countries.

Overall, we strongly suggest that international community should promote worldwide collaboration to enforce a ban of asbestos production and use and support countries in efforts to stop asbestos production and consumption within the next decade. The information generated from this study could explicitly help to inform decision makers on the need to ban asbestos in developing countries and worldwide.

Reference

1. Driscoll T, Nelson DI, Steenland K, *et al.* The global burden of diseases due to occupational carcinogens. American Journal of Industrial Medicine 2005**; 48:** 419-431.
2. Concha-Barrientos M, *et al.* Selected occupational risk factors. In: Ezzati M, *et al*, Eds. Comparative quantification of health risks: global and regional burden of diseases attributable to selected major risks factors. Geneva. World Health Organization, 2004: 1652-1801.
3. WHO. Asbestos. In: air quality guidelines, 2nd ed. Copenhagen: WHO 2000. Regional Office for Europe; http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf. (Accessed on April 23, 2011).
4. WHO. Asbestos in drinking-water: background document for development of WHO guidelines for drinking-water quality. 2003. Accessed on 24. 04. 2011. http://www.who.int/water_sanitation_health/dwq/asbestos.pdf.

5. Baguma D, Loiskandl W, Jung H. Water management, rainwater harvesting and predictive variables in rural households. Water Resources Management 2010; **24**(13): 3333-3348.
6. Saito T. Indirect estimation of asbestos concentration due to vehicles in particulate matter in the atmosphere and on roads by pyrolysis-gas chromatography. Journal of Analytical and Applied Pyrolysis 1995; **32**: 171-178
7. Lee RJ, Van Orden DR. Airborne asbestos in buildings. Regulatory Toxicology and Pharmacology 2008; **50**(2): 218-225.
8. The Lancet. Asbestos–related disease, a preventable burden. Editorial. www.the lancet.com 2008; **372(**9654): pp.1927.
9. Kouadio KI, Kamigaki T, Oshitani H. Strategies for communicable diseases response after disasters in developing countries. Journal of Disaster Research 2009; **4**(5): 298-308.
10. WHO. Environmental health criteria 203: Asbestos and other natural fibres. World Health Organization 1986; Geneva.
11. World Health Organization. Elimination of asbestos related diseases. Policy paper. www.who.int/occupational_health/publications/asbestosrelateddiseases.pdf. (Accessed on 26. 04. 2011).
12. Lin RT, Takahashi K, Karjalainen A, *et al*. Ecological association between asbestos related diseases and historical Asbestos consumption: an International analysis. Lancet 2007; **369**: 844-849.
13. World Health Organization. Asbestos: Elimination of Asbestos related diseases. Fact Sheet N°343, July 2010.
14. Peron L. Chrysotile. In: Canadian minerals yearbook, 2003: Ottawa, Natural Resources Canada 2003; **18**:1-11.
15. Le GV, Takahashi K, Karjalainen A, *et al*. National use of Asbestos in relation to economic development. Environmental Health Perspective 2010; **118**:116-119.
16. Joshi TK, Gutpa RK. Asbestos in developing countries: magnitude of risks and its practical implications. Int. J. Occupational Med Environ Health 2004; **17:** 179-185.

17. Harris LV, Kahwa IA. Asbestos: old foe in 21st century developing countries. Sci Total Environ 2003; **307**:1–9.

18. Virta RL. Worldwide asbestos supply and consumption trends from 1900 through 2003; Circular 1298. Department of interior, US. geological survey 2006 United Sates of America.

19. Chambers JM, Cleveland WS, Kleiner B, *et al*. Graphical methods for data analysis 1983, Wadsworth.

20. ESH. Engineering Statistics Handbook (ESH): NIST/SEMATECH e-Handbook of statistical methods 2011: http://www.itl.nist.gov/div898/handbook/. (Accessed February 16, 2011).

21. Shashanka B. Kalirajan KP. Incorporating regional variations in a macroeconometric model for India: A production frontier approach**.** Margin: The Journal of Applied Economic Research 2007 **1**: 167 DOI: 10.1177/097380100700100202.

22. Kalirajan KP, Shand RT. Economics in disequilibrium: An approach from the Frontier 1994. New Delhi: Macmillan.

23. Karirajan KP, Shand, RT. Frontier production functions and technical efficiency measures. Journal of Economic Surveys 1999; **13**(2): 149–172.

24. Sandfort J. Do government tools influence organizational performance? Examining their implementation in early childhood education. The American Review of Public Administration 2008; **38**: 4412-4438.

25. Hildreth C, Houck JP. Some estimators for linear model with random coefficients. Journal of American Statistical Association, 1968; **63**: 584–595.

26. Griffiths WE. Estimation of actual response coefficients in the Hildreth-Houck random coefficient model. Journal of American Statistical Association 1972; **67**: 633–35.

27. Kalirajan KP, Obwana MB, Zhao S. A. decomposition of total factor productivity Growth: the case of Chinese agriculture before and after reforms. American Journal of Agricultural Economics 1996; **78**(2): 331–38.

28. Karirajan KP, Shand RT. Sources of output growth in Indian agriculture. Indian Journal of Agricultural Economics 1997; **52**(4): 693–706.
29. Heitmueller A, Inglis K. The earnings of informal carers: Wage differentials and opportunity costs. Journal of Health Economics 2007; **26**(4): 821-841.
30. Perron L. Asbestos 2002: Web site at http://www.nrcan.gc.ca/mms/cmy/ content/2002/20.pdf. (Accessed on October 2, 2010).
31. United Nations, UN commodity trade statistics database 2004: Web site at http://unstats.un.org/unsd/comtrade. (Accessed on September 5, 2010).
32. Kazan-Allen, L. Asbestos and mesothelioma: Worldwide trends. Lung Cancer 2005; **49**(1): S3-S8.
33. Asukai Y, Valladares A, Camps C, *et al.* Cost-effectiveness analysis of pemetrexed versus docetaxel in the second-line treatment of non-small cell lung cancer in Spain: results for the non-squamous histology population. *BMC Cancer* 2010, **10:**26doi:10.1186/1471-2407-10-26.
34. Virta RL. Asbestos, in metals and minerals: US. geological survey minerals Yearbook 2005; **I** (8)1-6. (Also available on the Internet through http://minerals.usgs.gov/minerals/pubs/commodity/asbestos).
35. White MJ. Why the asbestos genie won't stay in the bankruptcy bottle 2002: http://weber.ucsd.edu/~miwhite. (Accessed on August 17, 2010).
36. Butler R. The cost of asbestos: Chemistry and Industry 2002; **18**: pp.10.
37. Moore P. Chrysotile in crisis: industrial minerals 2004; **439**: 56-61.
38. Tankahashi K, Kang SK. Towards elimination of asbestos-related diseases: a theoretical framework for international cooperation. Safety health work 2010; **1**: 103-106.
39. WHO. World Health Organization. WHO mortality database 2006. World health organization statistical information system (WHOSIS), Geneva.
40. CGE. Cancer gap with Europe 'not closed' (CGE). Press Association 2011. http://uk.news.yahoo.com/21/20110301/tuk-cancer-gap-with-europe-not-closed-6323e80.html. (Accessed on March 01, 2011).

41. WHO. Asbestos: elimination of asbestos-related disease. Fact sheet 2010 No. **343**. World Health Organization.

42. Clifton RA. Asbestos: US. Bureau of mines mineral commodity summary, July 1980; 14-15.

43. Laforest L, Yin D, Kocevar VS, *et al*. Association between asthma control in children and loss of workdays by caregivers. Ann Allergy Asthma Immunol. 2004; **93**(3): 265-71.

44. Blake CL, Van Orden DR, Banasik M, *et al*. Airborne asbestos concentration from brake changing does not exceed permissible exposure limit. Regul Toxicol Pharmacol 2003; **38**(1): 58-70.

45. Nicholson WJ, Perkel G, Selikoff IJ. Occupational exposure to asbestos: population at risk and projected mortality - 1980-2030. American Journal of Industrial Medicine 1982; **3**(3) 259-311.

46. Virta RL. Asbestos. Minerals Yearbook 2003. US. Department of Interior. Geological Survey 2003. United Sates of America

47. WHO World Health Organization. Elimination of Asbestos-Related Diseases 2006.http://whqlibdoc.who.int/hq/2006/WHO_SDE_OEH_06.03_eng.pdf. (Accessed on February 1, 2011).

48. HUKM. Hospital University Kebangsaan Malaysia. Cost of treatment data 2009; Kuala Lumpur, Malaysia.

49. World Bank. Gross national income per capita: Purchasing power parity in international dollars. World Development Indicators database, 2009. World Bank, New York.

50. Virta RL. Asbestos. Mineral yearbook 2009. US. Department of Interior. Geological Survey. United Sates of America.