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INCORPORATING ATMOSPHERIC ENVIRONMENTAL DEGRADATION IN RESEARCH EVALUATION OF OPTIONS FOR THE REPLACEMENT OF METHYL BROMIDE

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CONTENTS

ABBREVIATIONS

ACIAR:	Australian Centre for International Agricultural Research
UVB:	Ultraviolet B radiation
FRIM:	Forest Research Institute of Malaysia
CSIRO:	Commonwealth Scientific and Industrial Research Organisation
UNEP:	United Nations Environment Programme
UVA:	Ultraviolet A radiation
UVC:	Ultraviolet C radiation
ODP:	Ozone depletion potential
FAO:	Food and Agriculture Organization of the United Nations
GDP:	Gross domestic product
UVR:	Ultraviolet radiation

1. INTRODUCTION

1.1 The project and its objectives

This paper describes the projected net economic impact of a collaborative research project on the replacements for methyl bromide in timber for quarantine purposes (ACIAR PN 9406) proposed by CSIRO and FRIM[1] for funding by the Australian Centre for International Agricultural Research (ACIAR). The objective of the project is two-fold:

- First, to examine the effectiveness of various fumigants that are candidates for possible replacement of methyl bromide in quarantine fumigation of processed timber products from hardwoods including the following:
    - phosphine;
    - sulphuryl fluoride;
    - carbon bisulphide;
    - carbonyl sulphide;
    - methyl isothiocyanate; and
    - hydrogen cyanide.
- And second, to show that kilning of processed timber products from hardwoods, when done according to appropriate regimes, kills all insects in those products. The project may demonstrate that thermal disinfestation of wood is an alternative quarantine treatment for processed timber products from hardwoods. The project will recommend heat treatments appropriate for different sizes of processed timber products from hardwoods and for different insects which are of quarantine risk to Australia. While some of the research will involve the verification of models of heat transfer in hardwoods, the project intends to use existing knowledge of insect biology and heat-transfer processes.

The focus of the paper is not to justify or demonstrate the merit of the science in the proposed project. ACIAR has other processes for that. This paper estimates the potential benefits from the project and compares them to the potential costs of the project over a 30-year planning horizon. The evaluation framework includes the following impacts:

- the human health effects of methyl bromide;
- impacts of research in Malaysia, Papua New Guinea[2] and Australia that are the countries where the proposed ACIAR research project intends to focus its research effort; and
- price spillovers that arise when research in a significant producing country or region so shifts world supply as to change world prices.

1.2 The scope of the paper

This paper describes an economic evaluation of a research project that is at its proposal stage; and thus the gains discussed in the paper are in the future. Section 2 provides some background for the need to replace methyl bromide and the research project under consideration. Section 3 discusses the factors likely to determine the potential impacts of a research project on the replacement of methyl bromide. Section 4 uses the concepts of consumer and producer surplus to estimate the net welfare changes associated with the replacement of methyl bromide in the timber export industry. Section 5 summarises the results of the analyses and makes concluding remarks.

2. BACKGROUND

This section provides background information on methyl bromide and its use. It describes the uses of methyl bromide; and explores the reasons why it is under threat.

2.1 Methyl bromide: its sources and uses

The main motivation for this project is that continued use of methyl bromide as a fumigant upsets the atmospheric budget of methyl bromide. This atmospheric budget is controlled by the amount of methyl bromide added to the atmosphere from natural sources and from anthropogenic sources, and by the processes that remove methyl bromide from the atmosphere. Some of the methyl bromide that enters the atmosphere is removed mostly through chemical reaction with the hydroxyl radical (OH) and other chemicals in the troposphere. UNEP (1992b) lists the oceans as one of the natural sources of methyl bromide (CH_3Br) and also notes that, depending on the rate of air–sea exchange and the solubility of CH_3Br in water, ocean surface waters could be a significant but, up to now, unquantified removal process for CH_3Br. The anthropogenic source for addition of CH_3Br to the atmosphere is its use as a fumigant. Table 1 indicates the current pattern of usage in the different regions of the world.

Table 1. Methyl bromide sales[a] by category and region: (tonnes, 1990).

Region	Pre-planting fumigation of soil	Quarantine fumigation of commodities	Fumigation of structures (residential, commercial and industrial)	Chemical intermediates[d]	World Total	Percent of world total
North America	22 743	1219	1382	2757	28 101	42.2
South America	1140	361	120	–	1621	2.4
Europe[b]	16 582	991	644	–	19 119	28.7
North Africa	367	65	–	902	432	0.6
Rest of Africa	1381	325	132	–	1838	2.8
Asia[c]	8400	5265	906	34	14 605	21.9
Australia	693	185[f]	50	–	928	1.4
Total	51 306	8411	3234	3693	66 644	100
Percent of total	77.0	12.6[g]	4.9	5.5	100	
Percent of quantity used escaping to the atmosphere[e]	50%	67%[h]–80%	80%	0%	50%	

a: United Nations Environment Program (1992b).

b: Excludes countries formally in the USSR, however current production and use in these countries are thought to be small.

c: Excludes China and India, however current production and use in these countries are thought to be small.

d: Methyl bromide used for this purpose does not escape into the atmosphere.
e: United Nations Environment Program (1992a).
f: Australian Methyl Bromide Association (1992) estimated that in 1992 804 tonnes of methyl bromide were used in Australia with 21% of this used for quarantine fumigation, 75% for soil fumigation and 4% for other fumigation purposes.
g: In Australia, 70% of quarantine usage of methyl bromide is for fumigation of forest products.
h: This is the leakage in sealed enclosures as estimated by CSIRO's Stored Grains Research Laboratory.
– Nil.

Methyl bromide is used for quarantine and non-quarantine commodity treatments because it is rapidly effective (often requiring less than 24 hours) and toxic for pests on a wide range of commodities. Much of this use is for essential quarantine purposes. UNEP (1992a) lists commodities currently fumigated with methyl bromide to include durable food commodities (such as cocoa, coffee beans, grains, dried fruit, nuts), perishable food commodities (mainly fruits and vegetables) and non-food commodities (forest products, cut flowers, cotton, tobacco packaging, animal feedstuffs, artefacts and other commodities).

2.2 Why methyl bromide use is under threat

Table 1 indicates that about 80% of the methyl bromide used for quarantine fumigation escapes into the atmosphere. The overall lifetime of CH_3Br based on atmospheric removal processes is about two years (UNEP, 1992a). The bromine in methyl bromide is one of the chemicals (the other chemicals in this group contain chlorine) that is a catalyst in the atmospheric destruction of ozone.

Under the Montreal Protocol, methyl bromide is identified as an ozone-depleting chemical. It contributes to the destruction of ozone in the stratosphere—10 to 50 kilometres above sea level. About 90% of ozone is in the stratosphere. The scientific data appears to support an ozone-depleting potential[4] of about 0.7 for methyl bromide, with a much higher figure if estimates take into account methyl bromide's short atmospheric life[5] (Banks, 1994).
Ozone plays an important atmospheric role by controlling, in conjunction with atmospheric particles and clouds, the amount of solar ultraviolet (UV) radiation that reaches the Earth's surface (Roy and Giles, 1989). There seems to be a link between stratospheric ozone depletion and chlorine and bromine radicals. For example, Fraser (1992, p.35) notes:

> 'It has been recently established that levels of stratospheric ozone at all latitudes outside the tropics have declined over the past decade. This decline has been particularly severe at high latitudes and, in the Antarctic spring, the ozone decline has been clearly demonstrated to be due to relatively high levels of stratospheric chlorine and bromine radicals. Chlorine and bromine radicals are also thought to be responsible for the ozone decline at mid-latitudes, although the possible mechanisms are not well established.'

However some sceptics are of the view that the concern about ozone depletion and its effects on human health may be exaggerated. For example, this is the view of Professor F. Singer (see Pearce, 1994) who argues that:

> 'The main device used by researchers to measure ozone levels in the upper atmosphere confuses the gas with another pollutant, sulphur dioxide. What we may really be seeing is a fall in the amount of sulphur dioxide in the air, not ozone'.

A sensitivity analysis is done in section 5 to explore the implication of assuming that the human health impacts of ozone-depletion may not be high.

The ultraviolet spectrum has been divided, by those studying its biological effects, into three segments as follows:

Ultraviolet band	Electromagnetic ratio measured in nanometres (nm)
UVA	315–400
UVB	280–314
UVC	100–279

Source: Boal and Routh (1989)

Outside the earth's atmosphere, radiation from all three ultraviolet radiation bands (UVA, UVB and UVC) is present in the solar spectrum. Ozone, with an absorption band centred on 250 nanometres and extending beyond 350 nanometres, effectively eliminates all UVC radiation and about half of the UVB radiation (Boal and Routh, 1989). The ozone layer plays a role in reducing the intensity of the remaining UVB and UVA radiation.

The effect of a reduction in ozone is to increase the amount of UV radiation reaching the earth's surface. This in turn leads to sunburn, skin cancer, accelerated aging and eye diseases.

At the last meeting of the Montreal Protocol, Bangkok, 1993, a number of countries signed a non-binding declaration that supported rapid phase-out of methyl bromide (Appendix A). Banks (1994) notes that the 1995 meeting of the Montreal Protocol is likely to set a phase-out time for methyl bromide. The European Community is considering phase-out and restrictions independently of the Montreal Protocol. For example, one amendment put to the European Community Parliament recently sought to restrict importations of commodities whose producers use methyl bromide.

3. FACTORS THAT ARE LIKELY TO INFLUENCE THE POTENTIAL IMPACTS OF RESEARCH

The potential impact of research on the replacement of methyl bromide is likely to depend on the following factors:

- the size and structure of the industry;
- the current practices in treatment of timber;
- the current timber prices and postharvest costs;
- the current human health effects associated with the use of methyl bromide; and
- the likely efficacy and capacity to minimise product degradation of alternative practices.

3.1 The size and structure of the timber industry

The project assessed in this paper is part of a search for a treatment to replace methyl bromide in the quarantine fumigation of processed timber products from hardwoods. This paper assumes that restricting or banning the use of methyl bromide for quarantine fumigation of timber would affect trade in these products.

To evaluate the potential economic benefits of postharvest research affecting the forestry sector, it is necessary to estimate the quantity of the forest products targeted by research. The best source of world-wide production and consumption data are the United Nation's Food and Agriculture Organisation's Yearbook of Forest Products (e.g. FAO, 1990). However, the structure of the FAO's classification system is not apparent. Without an understanding of the linkages between forest products as one moves through processing stages, overestimation or underestimation of benefits may occur (Davis et al. 1989). Davis et al. (1989) provides a schema of the perceived market linkages and the total world production from FAO (1990) for each category and a summary of the FAO definitions of each product category. The economic evaluation in this paper uses data on processed timber products where these are defined as comprising two FAO categories: Sawnwood (non-coniferous) and wood-based panels (non-specific). These are defined as follows:

> Sawnwood (non-coniferous) stands for wood that is unplaned, planed, grooved, tongued, sawn lengthwise or produced by a profile-chipping process (e.g. planks, beams, joists, boards, rafters, scantlings, laths, boxboard, lumber) and planed wood which may also be finger jointed, tongued or grooved, chaffered, rabbeted, v-jointed, beaded from non-coniferous trees. Wood flooring is excluded. With few exceptions sawnwood exceeds 5 mm in thickness (Davis et al. 1989).
>
> Wood-based panels (non-specific) include veneer sheets, plywood, particle board and fibreboard compressed or non-compressed (Davis et al. 1989).

The sum of these two FAO categories of forest products provides an estimate of the production level of processed timber products used in this assessment. One sensitivity analysis in this paper examines the implications for the viability of different options for the replacement of methyl bromide—if it is assumed that none of the replacement technologies would be applicable to wood-based panels (non-specific).

Table 2 summarises the information on production, exports and imports of sawnwood and wood-based panels. These two timber products are used to estimate the production of processed timber products in the 24 countries and regions recognised in the analysis.

Table 2. Production of sawnwood and wood-based panels, 1990, (thousands of cubic metres).

	Sawnwood Production '000 cubic mtrs	Sawnwood Export '000 cubic mtrs	Sawnwood Import '000 cubic mtrs	Wood panels Production '000 cubic mtrs	Wood panels Export '000 cubic mtrs	Wood panels Import '000 cubic mtrs
BANGLADESH	73	0	11	8	0	0
CAMBODIA	43	0	0	2	1	0
CHINA	8035	39	22	3396	261	1331
INDIA	14834	2	5	442	17	2
INDONESIA	9000	614	0	9617	8591	0
LAOS	16	2	0	10	0	0
MALAYSIA	8183	5283	24	1630	1381	9
PAKISTAN	0	0	105	70	0	7
PHILIPPINES	841	77	0	488	223	0
SRI LANKA	16	0	2	10	0	8
THAILAND	1336	48	1485	270	12	34
VIETNAM	520	0	0	39	0	0
JAPAN	3336	23	1669	8616	93	4066
REST OF ASIA	4418	1316	3156	3134	1655	3881
AUSTRALIA	1629	15	254	1023	34	121
NEW ZEALAND	30	36	7	687	345	6
PAPUA NEW GUINEA	74	5	0	46	0	0
FIJI	53	0	0	16	7	1
REST OF OCEANIA	50	9	4	0	0	25
EUROPE	16194	2846	7044	37983	10396	14173
NORTH & CENTRAL AMERICA	19449	2397	2582	39153	5850	5129

SOUTH AMERICA	16136	835	190	4232	926	44
FORMER USSR	11300	130	106	12131	1076	108
AFRICA	6055	506	509	1935	309	339
TOTALS ('000 cubic metres)	121621	14183	17175	124938	31177	29284

Source: FAO (1990).

Table 3 contains information on the structure of the industry. The table makes a distinction between the ownership of the forest resource and the exploitation of the forest resource in the different parts of the world. There is a major distinction between the agents that own the forest resources all over the world, and the agents that harvest the resources. Table 3 suggests that the public sector owns about 77% of the world's forest resources, while the private sector owns 23% of the world's forest resources. The harvesting of forest products, however, is almost entirely by the private sector. Mather (1990, p. 103) provides the following summary of the situation:

> 'In many countries, parts of the state-owned forest are used privately (at least for timber production) under various agreements usually known as forest utilisation contracts or concessions. In the absence of the capability or will to utilise the forest resource themselves, governments use such arrangements as an alternative to alienating the state-owned forests to the private sector. Utilisation contracts concede to private users, often in the form of corporations, the right to harvest timber under prescribed conditions and in return for payment. Such concessions are associated especially with the use of tropical forests.'

Table 3. Structure of the forestry industry in selected countries.[a]

Country/Region	Ownership of forest resource	Exploitation of the resource
Bangladesh	Village homesteads (10%) and government(90%)[b]	Villagers and private sector concessions[b]
Cambodia		
China	Government[b]	Government owned firms[b]
India	Private individuals (94%) and government(6%)[b]	Private companies[b]
Indonesia	Public land[c]	Concession holders: Private sector[b]
Laos	Information not available	Information not available
Malaysia	Public : 95%, Private :5%[d]	Concession holders: Private sector[d]
Pakistan	Public : 92%, Private :8%[d]	Concession holders: Private sector[d]
Philippines	Public : 92%, Private :8%[d]	Concession holders: Private sector[d]
Sri Lanka	Public : 92%, Private :8%[d]	Concession holders: Private sector[d]
Thailand	Public : 92%, Private :8%[d]	Concession holders: Private sector[d]
Vietnam	Government[b]	Government[b]
Japan	Public : 42%, Private :58%[e]	Concession holders: Private sector[d]
Rest of Asia	Public : 92%, Private :8%[d]	Concession holders: Private sector[d]
Australia	Information not available	Information not available
New Zealand	Information not available	Information not available
Papua New Guinea	Forest land owned by the clan. Individuals own trees[d]	Concession holders: Private sector[d]
Fiji	Public :77% Private: 23%[d]	Private sector
Rest of Oceania	Public :77% Private: 23%[d]	Private sector
Europe	Public : 47%, Private :53%[d]	Concession holders: Private sector[d]
North &Central America	Public :73% Private: 27%[d]	Concession holders: Private sector[d]
South America	Public :55% Private: 45%[d]	Concession holders: Private sector[d]
Former USSR	Public: 100%[e]	Concession holders: Private sector[d]

Africa	Government [d]	Concession holders: Private sector[d]
TOTAL WORLD	Public: 77% Private: 23%[d]	

Sources:
a: Production figures from FAO (1990) are shown in Table 2.
b: Asia Pacific Forest Industries (1991).
c: Westoby (1989).
d: Early 1960s, Mather(1990).
e: Early 1980s, Mather(1990).

3.2 Current practices in the treatment of timber[6]

This section, drawing on Wallis (1970), briefly discusses the current practices in the treatment of forest products from the time a tree is felled to the point of export; and indicates the role of methyl bromide in these practices. The discussion is intended to give an overview of the processes involved in the production of a processed timber product. Wallis (1970) gives a more detailed description of these processes.

Harvesting wood and minimal processing of timber

Every year, about 3000 million cubic metres of wood are harvested as logs. Of this amount, slightly more than half is burned as fuel for heating and cooking, most of it directly but some in the form of charcoal (Westoby, 1989).

Some wood is used as pit props, telegraph poles, fencing and the like. These are recognisably parts of a tree, and are often in the shape of a log. They may be minimally treated with preservatives to reduce deterioration of timber due to from weather, fire, fungi, insects and marine borers. The method of application may be by dipping in a chemical, brushing or spraying with a preservative or some other method (see Wallis, 1970).

Transport of round logs from the forest

Transport is a significant part of postharvest costs of forest products. As Westoby (1989) notes:

> 'Historically the price of wood has generally been determined by the cost of getting it where it was wanted, not by the cost of growing it, renewing it or replacing it. This was true of the northern temperate forests until quite recent times, and it is still true of the tropical forests'

Usually round logs are transported to a sawmill for processing before they are transported to further destinations. At the sawmill logs are sorted and measured to calculate the wood content of logs.

Primary preparation cuts

This is a process where a log is broken down into a number of flitches which are of a size and weight manageable by the crew. The flitches are not cut to a definite size. At the same time high quality logs are segregated from low quality stock.

Steaming or heating in water to soften wood

Before a flitch is sliced to veneer it is either heated in water, or steamed, to soften the timber. Various times and degrees of heating are necessary according to the species treated and experience with individual timbers is necessary to achieve best results.

Secondary preparation cuts

At this step the flitches are re-cut into pieces, squared and cut to size ready for the final stage. This is the most important part in the sawing process, since the saw-mill end-products depend on the way these cuts are made.

Ripping off

This is the final stage in the process of sawing logs for board production and involves passing through the saw again and again, a board being ripped off from the gauge side of the saw with every cut, until the piece is completely sawn up. Several methods can be used at this stage, including slicing, semi-rotary slicing, sawing or rotary cutting.

Dressing and moulding

Dressing is a process where timber is mechanically planed by passing the surface or surfaces of the timber across the cutting edges of fast revolving knives or cutters. According to the design of the individual machine, timber can be planed on any face or all four sides in one operation, and may be finished to a flat surface or shaped (moulded) to a required pattern.

Making a timber stack

To make a stack, successive layers of boards up to 6–8 feet in width are placed above one another, and separated by small strips. The length of the stacks varies from about 20–25 feet. It is necessary to convert a parcel of timber into a stack before timber is seasoned.

Seasoning or drying of timber

The aim of seasoning is to dry a parcel of timber to the required equilibrium moisture content in the minimum time and with minimum degradation. It is important to dry veneers without delay in order to prevent the growth of mould which may occur when veneers are closely stacked in damp conditions. There are two principal methods employed for drying timber: natural or air drying and kiln drying. For the natural or air drying of timber, the stacks of timber are exposed to the atmospheric conditions. A major disadvantage of this method of seasoning is that it is not possible to control the temperature, the relative humidity and the air circulation which are the three most important determinants of drying rate.

In a timber drying kiln it is possible to control the temperature, the relative humidity and the air circulation. Hence they can be used to control the rate of drying and produce seasoned timber of very high quality. A common way to dry veneers is to use a suitable type of seasoning kiln equipped with steam coils and a blower.

Fumigation with methyl bromide

Fumigation of timber products with methyl bromide occurs either pre-shipment at the point of export, en-voyage between the port of export and the importing country, or on arrival in the importing country before the products are cleared by quarantine. Importation of a product subject to infestation by quarantine-risk insects is often only permitted if the product is fumigated in the country of origin or at the ports of destination (UNEP, 1992a, Taylor, 1994). Table 1 shows that methyl bromide is widely used for quarantine fumigation. The exceptions are countries formerly in the USSR, China and India where current production and use of methyl bromide is low (UNEP, 1992b). For trade between Malaysia and Australia, the insects that are quarantine risks and require fumigation include lictids, bostrichids, dermestids, dry wood termites, *Lyctus brunneus, Xyleborus ferrugineus, Trogoderma* and *Hylotrupes* (ACIAR, 1994).

The project discussed in this paper intends to investigate first, whether the heat treatment under kiln drying of timber disinfests timber of all insects and thus make fumigation with methyl bromide unnecessary. Second, the project will explore alternative fumigants which could be used in place of methyl bromide in the quarantine fumigation of timber.

3.3 Current timber prices and postharvest costs

FAO (1990) provides aggregate-weighted world export and world import unit values for various categories of forest products. However, for some countries, these unit values seem to suggest that, for some categories of forest products, the free-on-board (fob) export prices were less than the cost, insurance and freight (cif) prices for imports. Figures on stumpage are not available for most countries and, where they are available, do not reflect market prices because of they are often government determined and thus not the outcomes of market demand and supply forces. This study uses the price of US$368.50 per cubic metre (the export price of dark red meranti sawnwood in Malaysia, Peninsula) published in FAO (1992) as the basis for an estimate of price of processed timber products.

The project on the replacement of methyl bromide for quarantine fumigation of hardwoods is likely to affect the postharvest processing and other costs incurred between the port of export and the port of the importing country.

Let z_{ci} represent the average cost of transporting processed timber products from hardwoods between the port of export in country c_i to the ports of the importing countries c_j $j \neq i$ and $j = 1,2,3,\ldots, c^*$. The average cost depends on a number of factors as follows:

$$z_{ci} = f(\theta_{cic1}, \theta_{cic2}, \theta_{cic3}, \ldots, \theta_{cic*}, (\mathit{l}[D_{cic1}, D_{cic2}, D_{cic3}, \ldots, D_{cic*}]) \qquad (1a)$$

$$= \theta_{cic1}\lambda_{cic1} + \theta_{cic2}\lambda_{cic2} + \theta_{cic3}\lambda_{cic3} + \theta_{cici-1}\lambda_{cici-1} + \theta_{cici+1}\lambda_{cici+1} + {}_{cic*}\lambda_{cic*} \qquad (1b)$$

with

$$\lambda_{cicj} = D_{cicj}E_{cicj}F \qquad (1c)$$

where:

θ_{cicj} is the proportion of country c_i's total exports whose destination is country c_j

D_{cicj} is the distance in miles between the main port in country c_i and the main port in country c_j.

λ_{cicj} is a scalar that gives the distance weighted per unit cost of transporting processed timber products from hardwoods between the port of export in country ci to the ports of the importing countries c_j $j \neq i$ and j = 1,2, 3,..., c* with c* = 24 in this paper;

E_{cicj} is an estimate of the ocean freight rate for transporting a tonne of timber products from the main export port in country c_i to a representative port in the importing country c_j. These estimates are based on the estimates in Table 4.

Table 4. Ocean freight rates for selected routes and commodities, 1990–91.

Port of origin	Port of destination	Size of vessel	Cost	Commodity
United States Gulf ports	Rotterdam	Over 50 000 tonnes	$ US 12.75[a]	Wheat
United States Gulf ports	Black Sea (Commonwealth of Independent States)	20 000– 50 000 tonnes, but excludes CIS and US flag ships	$ US 26.00[a]	Wheat
United States Gulf ports	Egypt (Alexandria)	Over 30 000 tonnes	$ US 18.40[a]	Wheat
United States Gulf ports	Bangladesh	Over 40 000 tonnes	$US 28.08[a]	Wheat
United States Gulf ports	East Africa (Sudan)	15 000 to 25 000 tonnes	$ US 60.50[a]	Wheat
North Pacific ports	China	Over 30 000 tonnes	$ US 18.25[a]	Wheat
North Pacific ports	Japan	15 000 to 19 999 tonnes	$ US 26 20[a]	Wheat
United States	Venezuela		$ US 17.00[b]	Wheat
Australia (New Castle or Port Kembla)	Continent (Europe)	50 000 to 60 000 tonnes of coal	$ US 14.50[c]	Coal

a: FAO(1994)
b: FAO(1993)
c: Drewry Shipping Consultants (1985)

For example take the case of transport costs between a port in Africa and a port in Bangladesh. These costs are estimated as follows. First Table 4 shows an estimate by FAO (1994) that in March 1994 the cost of transporting a tonne of wheat from a United States Gulf port to East Africa (Sudan) was about US$ 60.50. The distance from the United States gulf port to Sudan and the distance between Bangladesh and Sudan are known[7]. Thus it is possible to estimate the cost per ton-kilometre of transporting a ton of wheat between a United States gulf port and Sudan. This process is repeated for other pairs of ports.

F is a conversion factor used to change costs per ton-kilometre into costs per cubic metre which is necessary because the FAO (1990) on forest products used in the analysis is in cubic metres. FAO(1990) estimates that 1 tonne of wood is equivalent to 1.37 cubic metres.

The trade weights or proportions, θ_{cicj}, are derived from data on directions of trade published in FAO (1990). The distances between different countries were estimated using information on the distance between major ports or cities of nations. Table 4 shows estimates of the cost of transport of some commodities between pairs of countries.

Table 5 summarises z_{0ci} the 'before research' average cost of processing and transporting a tonne of processed timber products from hardwoods between the port of export to the ports of the importing countries. The project on the replacement of methyl bromide is likely to affect the cost of transporting (modelled to include the costs of fumigating) a tonne of processed timber products from hardwoods between the port of export to the port of the importing country. The effect on prices of processed timber products in a given country or region depends on whether the country or region is a non-trader, net-exporter or net-importer of processed timber products. Table 5 gives information on the trade status in 1990 of the different countries and regions based on data from FAO (1990).

Table 5. Estimates of the 'before research' average cost of transporting processed timber products between the port of export in a given country to the ports of importing countries, $A/cubic metre.

Country/Region	Average cost	Trade status
Bangladesh	$A2.35	Net importer
Cambodia	$A1.47	Net exporter
China	$A6.65	Net importer
India	$A5.50	Net exporter
Indonesia	$A13.07	Net exporter
Laos	$A8.68	Net exporter
Malaysia	$A12.57	Net exporter
Pakistan	$A7.84	Net importer
Philippines	$A4.29	Net exporter
Sri Lanka	$A3.53	Net importer
Thailand	$A4.29	Net importer
Vietnam	$0[a]	Non trader
Japan	$A8.90	Net importer
Rest of Asia	$A3.60	Net importer
Australia	$A23.04	Net importer
New Zealand	$A16.53	Net exporter
Papua New Guinea	$A13.39	Net exporter
Fiji	$A19.09	Net exporter
Rest of Oceania	$A17.57	Net importer
Europe	$A32.27	Net importer
North and Central America	$A19.20	Net exporter
South America	$A30.05	Net exporter
Former USSR	$A31.38	Net importer
Africa	$A11.24	Net importer

a: The entry of zero denotes that the country neither imports nor exports processed timber products from hardwoods.

3.4 Human health effects associated with the use of methyl bromide

The human health effects associated with the use of methyl bromide arise from the fact that methyl bromide is a catalyst in the ozone depletion process. Ozone depletion leads to an increase in the amount of ultraviolet radiation reaching the earth. Barton and Paltridge (1979) have calculated the ‘mean daily erythemal dose’ of ultraviolet radiation—a measure of biological effectiveness of ultraviolet radiation—for various locations in Australia. A summary of their estimates is reproduced in Figure 1.

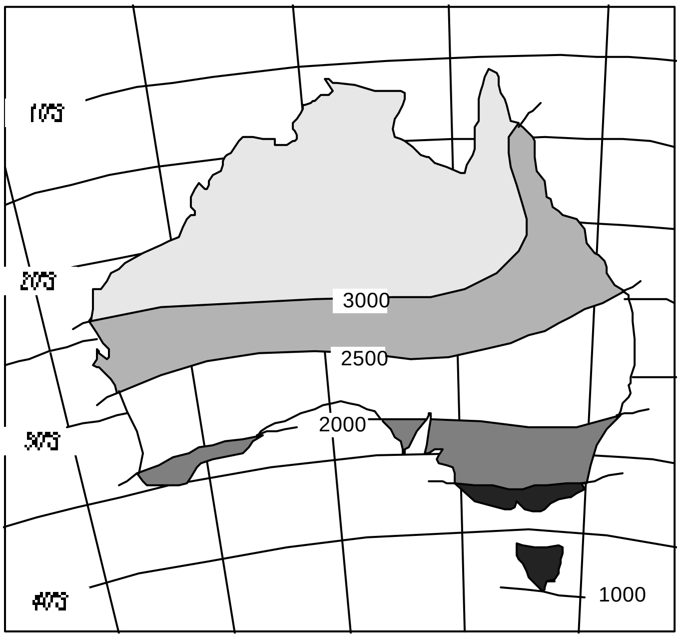

Figure 1. Annual mean distribution of daily total erythemal dose over Australia
Source: Barton and Paltridge (1979)

A first step in quantifying the effect of replacing methyl bromide on the incidence of illnesses induced by ultraviolet radiation B was to assign to a latitude band each of the countries and regions in the analysis. Table 6 shows the assignment of population in the 24 countries and regions to 5 latitude bands used for the analysis of human health effects.

Table 6. Assignment of selected countries (millions of people) of the world to 5 latitude bands[a] for analysis of human health effects of methyl bromide.

	Latitude Bands				
Country/Region	25° South to 25° North	25° to 28°	28° to 32°	32° to 40°	Over 40°
Bangladesh	115				
Cambodia	69				
China			446	669	
India	849				
Indonesia	191				
Laos	4				
Malaysia	17				
Pakistan	113				
Philippines	67				

Sri Lanka	17				
Thailand	56				
Vietnam	68				
Japan			124		
Rest of Asia	261		166		
Australia	0.15	4.5	7.6	4.4	0.45
New Zealand					3.4
Papua New Guinea	3.8				
Fiji	0.8				
Rest of Oceania	4.2				
Europe				411	274
North and Central America	87			306	27
South America	288				
Former USSR				291	
Africa	606		35[b]		

a: The effects in the southern and northern hemispheres are assumed to be symmetrical.
b: South Africa.

The medical literature indicates that there are three main human health effects of a chlorine- and bromide-related reduction in ozone indicated below.

- Sunburn (erythema). This is the most commonly encountered effect of ultraviolet radiation.
- Skin cancer and accelerated aging. There are three major types of skin cancer: basal cell carcinomas (BCC), squamous cell carcinomas (SCC) and malignant melanomas. The first two types of skin cancer are easy to treat. Malignant melanomas are the rarest and most dangerous forms of skin cancer. A 1% increase in ultraviolet radiation is likely to lead to a greater than 1% increase in the incidence of skin cancer (National Health and Medical Research Council, 1989).
- Eye disease. The most common eye diseases caused by ultraviolet radiation are conjunctivitis, pterygium and senile cataracts. Conjunctivitis is an inflation of the membrane covering the interior portion of the eye ball. Pterygium is a wing-shaped vascular thickening of the membrane covering the eyeball that spreads into the cornea, usually on the nasal side of the eye. A cataract is a partial or complete opacity of the lens of the eye and is a common form of blindness. A 1% increase in ultraviolet radiation is estimated to increase the incidence of pterygium by 2.5% in Aborigines and by 14% in non-Aborigines and senile cataract by 0.6–0.8% in non-Aborigines (National Health and Medical Research Council, 1989).
- Immunological effects. An increase in exposure to ultraviolet radiation may reduce the skin's immune responses. An increase in exposure to ultraviolet radiation may lead to an increase in the severity and frequency of several diseases. These include cancer, viral diseases and fungal infection (National Health and Medical Research Council, 1989).

Bryant et al. (1992) reported the incidence rates of ultraviolet radiation B-induced health conditions in Australia. These estimates are summarised in Table 7 together with estimates of the levels of ultraviolet radiation exposure in the different locations. Data from Stolarski et al. (1992) suggest that relationships can be shown between ozone depletion trends and latitude bands. Within those latitude bands the ozone depletion trends are almost identical, irrespective of longitude.

Table 7. Daily erythemal ultraviolet radiation B dose and the incidence[a] of ultraviolet radiation induced human health conditions in Australia.

Variable	Tasmania	Victoria	NSW & SA	WA & QLD	NT
Latitude[b]:	40º South or higher	32º S to 40 to 40º S	28º South to 32º South	25º South to 28º South	0º to 25º South
UVB dose[c]	1050 to 1150	1500 to 1750	1800 to 2000	2150 to 2750	3000
Incidence of:					
Skin cancer-BCC[d,f]	254 to 279	386 to 488	511 to 615	708 to 1238	1563
Skin cancer-SCC[e,f]	76 to 83	116 to 146	153 to 184	212 to 370	467
Melanoma skin cancer[g]	16	19.5	20	25 to 41.5	41.5
Pterygium[h]	0	100 to 200	350 to 480	590 to 1080	1350
Cortical cataracts[i]	4714	6149 to 7174	7379 to 8199	8814 to 11273	12298

a: Incidence rates are number of cancers per 100 000 of population. Bryant et al. (1992, p.63) points out the incidence rates refer to the number of cancers and not the number of people. Individuals, especially as they become older, generally can have more than one skin cancer. Marks (1989, p.74) estimates that over 80% of people with solar keratosis have on average 6 to 7 lesions per person.

b: deduced from the map by Barton and Paltridge (1979).

c: Bryant et al. (1992, Table 4.3).

d: Basal cell carcinomas—non melanoma.

e: Squamous cell carcinomas—non melanoma.

f: The susceptibility to non-melanocytic skin cancer is related to skin to colour. Black or dark skinned people are less susceptible than white to non-melanocytic skin cancer. However, even among white people: 15 to 25% of people always burn, never tan if exposed to strong sunlight; 40 to 50% of people burn first and then tan; 20 to 25% of people just tan and never burn (Marks, 1989).

g: Bryant et al. (1992, Table 4.5). Rates are based on 1987 data.

h: Bryant et al. (1992, Table 4.7). Rates are based on 1984 data. This is an eye medical condition related to exposure to excessive ultraviolet radiation.

i: Bryant et al. (1992, Table 4.9). Rates are based on 1990 data. Cortical cataracts are an eye condition affecting the cornea of the elderly. Bryant et al. (1992, p. 85) reported that in the United States senile cataracts affected 12.3 % of the population with the incidence increasing from 3.5% under the age of 65 to 41.4% in the over 75 year age group. There are little reliable data for the prevalence of cataracts in the overall Australian population.

The latitude bands used are shown in the second row of Table 7. For each latitude band, the incidence of UVB-induced medical conditions in Table 7 approximate the incidence of these conditions in other countries of the world. That is, changing the longitude on a map of the world while staying within the same latitude band leaves the erythemal radiation dose—in the third row of Table 7—almost constant and the incidence of UVB-induced medical conditions approximately the same.

Thus Table 7 approximates the incidence of UVB-induced medical conditions in Australia and Table 8 shows the incidence of UVB-induced medical conditions in the other countries.

Table 8. The incidence of UVR-induced medical conditions per 1 000 000 of population in selected developing countries

Country/Region	Eye diseases	Melanoma of skin	Other skin cancers
Bangladesh	322	40	549
Cambodia			
China	4	5	5

India	14	13	36
Indonesia	10	27	145
Laos	28	1	460
Malaysia	3	0	7
Pakistan	60	6	216
Philippines	11	0	38
Sri Lanka	16	13	93
Thailand	28	1	460
Vietnam	91	19	501
Papua New Guinea	52	108	538
Fiji	2	3	29
Rest of Oceania	2	3	29
Africa	30	25	27

Source: Parkin (1986).

Discovery of a replacement for methyl bromide in the quarantine fumigation of processed timber products from hardwoods will reduce the rate of ozone depletion in the world, which in turn is likely to reduce the amount of ultraviolet radiation reaching the earth. This is likely to translate into reduced incidence of the human health conditions listed in Table 7.

4. QUANTIFICATION OF THE WELFARE IMPACTS OF A TECHNOLOGY TO REPLACE METHYL BROMIDE

This project development assessment includes the following welfare impacts of a technology to replace methyl bromide:

- the impacts due to a reduction in the incidence of ultraviolet radiation B-induced medical conditions;
- the impact on the cost of quarantine treatment of timber in the countries collaborating in the research project, namely, Malaysia, Papua New Guinea and Australia; and
- the impacts on the world price of processed timber products from hardwoods and the trade dependent price spillovers to other countries and regions in the world.

The rest of this section briefly describes how each of these impacts was quantified and evaluated.

4.1 The welfare impacts due to a reduction in environmental pollution and in the incidence of associated ultraviolet radiation-induced diseases

There are two main approaches to the study of disease in a community. One approach determines the disability-adjusted life years lost due to premature death and increased morbidity. An example of this approach is that by the World Bank (1993b). The aim in computing life years lost is to give some impression of the nature and degree of ill health in a community. This approach does not generally produce a monetary cost of disease. A second approach estimates the monetary cost of disease. An examples of this approach is Crowley et al. (1992). This paper uses the second approach because it generates a meaningful, though partial, monetary measure of the cost of disease. It is partial because it does not cover all impacts of disease. For example, it does not incorporate the effects of disease on quality of life or human suffering, for which satisfactory measures are still being developed (Crowley et al. 1992).

In this paper, the cost of the human health effects of ultraviolet radiation covers two categories of the cost:

- the cost of mortality which relates to the cost of productive capacity lost when people die before reaching the end of their productive life; and
- the cost of morbidity.

There are two main methods for determining the value of life (Crowley et al. 1992): the human capital approach; and the willingness-to-pay. The human capital method equates the value of life with the present value of expected future earnings. The willingness-to-pay method, which usually leads to higher estimates of value of life, uses contingency valuation surveys to ask people how much they would be willing to pay to avoid different levels and types of risks. The willingness-to-pay approach is inappropriate when people surveyed cannot perceive the risk the cost of which they are to assess. This paper uses the human capital approach to estimate the cost of life.

Davis and Lubulwa (1993) suggested that estimates of human health benefits could be based either on labour market impacts or on the impact on the market for medical services. This paper estimates human health effects based on the labour market. The human health effects that this paper measures are not reflected in the market for processed timber products. Alston et al. (forthcoming) notes that:

> 'Unless the welfare implications of externalities are explicitly accounted for in the analysis, the usual calculation of consumer and producer surplus does not include them.'

However these are likely to be reflected in the labour market. For example, premature death and morbidity of employees due to medical conditions attributable to the use of methyl bromide reduce the supply of labour in an economy. Thus a replacement technology that is non-ozone depleting is likely to shift the labour supply curve in an economy to the right.

An estimate of the welfare impacts in country c due to a reduction in environmental pollution and in the incidence of associated ultraviolet radiation-induced diseases is given by equations (2a)–(2c).

$$\Delta ES_c = kL_{oc} + \varepsilon_{dL}\varepsilon_{sL}L_{oc}k_c^2/2P_{oc}(\varepsilon_{sL} + \varepsilon_{sL}) \quad (2a)$$

$$k_c = HH_c/L_{oc} \quad (2b)$$

$$HH_c = \Sigma_i(D^f_{jig}L^f_g) + \Sigma_i(D^{nf}_{jig}L^{nf}_g) \quad (2c)$$

where:

k_c is the absolute reduction per capita, in country c's human health related production loss (measured as expected future earnings forfeited) due to the research impact. It is the vertical distance between the 'before research' and 'after research' labour supply function in country c.

L_{oc} is population in country c 'before research' over 15 years of age.

ε_{dL} is the elasticity of demand for labour.

ε_{sL} is the elasticity of supply for labour.

P_{oc} is the gross domestic product per capita before research in country c.

HH_c is country c's total annual human health related production loss (measured as expected future earnings forfeited) as a result of medical conditions j, j = 1, 2,.., J, induced by ultraviolet radiation.

D^f_{jic} is the number of people dying (superscript f denotes fatal) from medical condition j, in latitude band i, in country c due to exposure to ultraviolet radiation.

D^{nf}_{jic} is the number of non fatal (nf) cases of medical condition j, in latitude band i, in country c due to exposure to ultraviolet radiation.

L^f_{gc} is the value (measured as expected future earnings forfeited) of a life of someone dying prematurely at age g in country c;

L^{nf}_{jc} is an estimate of the annual human health related value of production lost due to a person suffering from a non-fatal UVR-induced medical condition j in country c.

The value (measured as expected future earnings forfeited) of a life for a person dying in country c at age g is estimated using the functions in equations (3) to (5) which define the present value of an annuity:

$$L^f_{gc} = \{\pi[(1+\zeta)^{\psi}\angle 1]/\zeta(1+\zeta)^{\psi}] \quad (3)$$

$$\pi = GDP/12 \quad (4)$$

$$\psi = 12(\Omega\angle\Gamma) \quad (5)$$

where:

π is an estimate of the monthly wage

GDP is the nation's Gross Domestic Product

ζ is the interest rate per month

ψ is the number of months of life lost due to premature death

Ω is the country's average life expectancy measured in years

Γ is the age at death due to a medical condition induced by exposure to ultraviolet radiation

$L^{nf}_{c,}$ the estimate of the annual human health related production loss due to a person suffering from a non-fatal UVR-induced medical condition j in country c is estimated using equations (6):

$$L^{nf}_{jc} = E_j \varphi_c \qquad (6)$$

where:

E_j the estimate of the annual human health related production loss or income foregone as a result of a person suffering from a non-fatal UVR-induced medical condition j in Australia. These estimates are summarised in Table 9.

Table 9. Average medical cost of disease for non-fatal UVR-induced medical conditions (These are equal to E_j in equation 6).

Non fatal medical condition	Cost ($ A 1990)
Non-melanoma SCC	1938
Non-melanoma BCC	854
Melanoma	11 103
Pterygium	460
Cataracts	763

Source: Bryant et al. (1992, Table 6.22).

φ_c is a function of the ratio of gross domestic product (GDP) in country c to Australia's gross domestic product.

φ_c = 1 if the GDP in country g is equal or greater than the GDP in Australia;

φ_c = the ratio of (GDP) in country c to Australia's GDP, otherwise.

In countries that are as rich as, or richer than, Australia the medical cost of disease would be approximately equal to the Australian estimate. However, in countries that are poorer than Australia, the medical cost of disease is likely to be much lower than in Australia. The medical costs of disease in Table 10 include the cost of hospitalisation, the cost of general practitioners and specialists and pharmaceuticals.

Table 10. Parameters used in estimation of annual human health welfare benefits due to a reduction in UVR-induced medical conditions after replacement of methyl bromide with a non-ozone depleting quarantine treatment for processed timber products from hardwoods.

Country/ Region	Value of a life lost due to a fatality from non-melanoma SCC[b]	Value of a life lost due to a fatality from non-melanoma BCC[c]	Value of a life lost due to a fatality from melanoma[d]	National GDP/ Australian GDP (φ_g)

	Lf_{gc} *for non-melanoma SCC estimated as in Equation 2 and 3*	Lf_{gc} *for non-melanoma BCC estimated as in Equation 2 and 3*	Lf_{gc} *for melanoma estimated as in Equation 2 and 3*	
	$'000, 1994	$'000, 1994	$'000, 1994	
Bangladesh	0[a]	0[a]	945	0.014
Cambodia	0[a]	0[a]	0[a]	0.027
China	3446	1136	4486	0.027
India	0[a]	0[a]	3012	0.027
Indonesia	0[a]	0[a]	3914	0.038
Laos	0[a]	0[a]	0[a]	0.015
Malaysia	21 365	7043	27 817	0.165
Pakistan	0[a]	0[a]	2681	0.031
Philippines	3891	0[a]	7375	0.051
Sri Lanka	4771	1573	6212	0.037
Thailand	6576	0[a]	11 411	0.077
Vietnam	1512	0[a]	2624	0.018
Japan	231 836	159 829	264 274	1.454
Rest of Asia	2345	0[a]	4069	0.027
Australia	159 448	109 925	181 760	1.000
New Zealand	99 545	52 512	120 734	0.690
Papua New Guinea	0[a]	0[a]	5 031	0.066
Fiji	20 834	12 007	24 811	0.140
Rest of Oceania	0[a]	0[a]	5 031	0.066
Europe	234 575	123 745	284 507	1.627
North and Central America	254 421	146 627	302 985	1.714
South America	15 666	0[a]	27 182	0.183
Former USSR	86 984	0[a]	126 172	0.791
Africa	0[a]	0[a]	2762	0.029

a: The cost of life of zero means that the age at which this medical condition leads to the death of an individual exceeds the life expectancy in the country. The average age at death is estimated on the basis of the Australian experience, (Bryant et al. 1992, Table 4.4, Table and Table 4.6).

b: The pre-retirement median age at death from this disease is 65 years.

c: The pre-retirement median age at death from this disease is 55 years.

d: The pre-retirement median age at death from this disease is 45 years.

The number of people dying of a medical condition j, in latitude band i, induced by exposure to ultraviolet radiation in country c is given by the following equation:

$$Df_{jic} = C_{ji}N_{ig}\beta_1\beta_2\beta_3\beta_4\beta_{j5} \qquad (7)$$

where:

C_{ji} is the estimated incidence of medical condition j per 100,000 of population, in latitude i.

N_{ic} is the number of people exposed to ultraviolet radiation in latitude band i in country c.

β_1 is the share of methyl bromide in the global anthropogenic depletion of the ozone layer. Here an estimate of 2% for β_1 is used (Bryant et al. (1992, p. 44).

β_2 is the share of quarantine fumigation in total usage of methyl bromide. The estimate used in this paper for β_2 is 12.6% (see Table 1).

β_3 is the share of fumigation of forest products in the total quarantine fumigation use of methyl bromide. Estimates in Australia suggest that β_3 is equal to about 70% (see Table 1).

β_4 is the proportion of methyl bromide used for quarantine fumigation of commodities that escapes to the atmosphere. On the basis of Australian experience, β_4 is about 0.8.

β_{j5} is the proportion of the cases of medical condition j which are fatal. Only three of the UVR-induced medical conditions are known to lead to death in some cases. These are SCC non-melanoma with a β_{j5} value of 0.0380, BCC non-melanoma with a β_{j5} value of 0.0030 and malignant melanoma with a β_{j5} value of 0.3205. The other UVR-induced medical conditions do not lead to fatalities (Bryant et al. 1992, p 171).

In columns 2, 3 and 4, Table 10 gives the estimates of values (measured as expected future earnings forfeited) of a life of someone dying prematurely at age g in country c, estimated using equation (3). There are three estimates for each country since there are three UVR-induced medical conditions that are known to result in fatalities. The estimates are different for the different UVR-induced fatalities because the average age of death is different for each of the medical conditions. Second, Table 10 shows the country specific values of φ_c which are used to estimate production losses of UVR-induced medical conditions.

In estimating the human health benefit from a reduction in the use methyl bromide for quarantine fumigation of timber, this paper considers three possible cases:

- the low human health benefit case;
- the most likely human health benefit case; and
- the high human health benefit case.

These three cases are discussed in more detail in section 5.3 on sensitivity analyses. Table 11 summarises the estimates of the human health benefits under the three sets of assumptions. In the rest of the paper the most likely values of human health benefits are used.

Table 11. Estimates of human health benefits due to the replacement of methyl bromide by a kilning treatment which is non-ozone depleting, where processed timber products are defined to include sawnwood (non-coniferous) and wood-based panels.

	Low ($A, 1994)	Most likely ($A, 1994)	High ($A, 1994)
BANGLADESH	0.00	0.28	16.54
CAMBODIA	0.00	0.02	0.90
CHINA	0.00	0.51	9.70
INDIA	0.00	0.12	2.94

INDONESIA	–0.04	0.08	1.60
LAOS	0.00	0.00	0.01
MALAYSIA	0.86	0.00	0.00
PAKISTAN	0.00	0.01	0.37
PHILIPPINES	0.00	0.00	0.02
SRI LANKA	0.00	0.00	0.07
THAILAND	0.00	0.02	0.30
VIETNAM	0.00	0.01	0.49
JAPAN	0.00	24.97	24.97
REST OF ASIA	–0.02	0.06	1.51
AUSTRALIA	–0.01	1.96	1.96
NEW ZEALAND	0.00	0.11	0.15
PAPUA NEW GUINEA	0.00	0.01	0.21
FIJI	0.00	0.00	0.00
REST OF OCEANIA	0.00	0.00	0.00
EUROPE	–0.13	65.35	65.35
NORTH & CENTRAL AMERICA	–0.03	41.30	41.30
SOUTH AMERICA	0.00	3.32	31.03
FORMER USSR	0.00	6.76	8.36
AFRICA	–0.01	0.14	3.34
TOTAL	0.63	145.05	211.11

a: The values for the most likely scenario and the high cost scenario are equal because in the base year, the ratio of Australia's Gross domestic Product to that of the average for Europe was 1. Similarly in the base year, the ratio of Australia's Gross domestic Product to that of the average for north and Central America was 1. (See equation 6).

4.2 The impact on the cost of quarantine treatment of timber

Table 12 summarises the possible technologies for the replacement of methyl bromide. Though methyl bromide is included in Table 12, it is used in the analysis as a reference technology only.

Table 12. Quarantine relevant timber insect pests, technological options for the replacement of methyl bromide and estimates of the most likely doses (grams per cubic metre) of various fumigants and the heat levels under the kilning (heat) option required to meet quarantine requirements.

No	Insect type	Heat to kill all insects in wood under PN9406[b]		Heat to kill all insects in wood: current quarantine rules		Methyl bromide		Phosphine in cylinders		Phosphine with a pellet generator		Sulfuryl flouride		Carbon bisulphide	
		OPT[a]	PES[a]	OPT[b]	PES[b]	OPT	PES	OPT	PES	OPT	PES	OPT	PES	OPT	PES
1–3	Lictids (Species 1–3)	50°C	60°C	64	64	48[c]	48[c]	5[e]	NK[f]	5[e]	NK[f]	64[g]	64[g]	100	150
4–7	Bostrichids(Species 1–4)	50°C	60°C	64	64	48[c]	48[c]	5[e]	NK[f]	5[e]	NK[f]	64[g]	64[g]	100	150
8	Dermestids	50°C	60°C	64	64	48[c]	48[c]	5[e]	NK[f]	5[e]	NK[f]	64[g]	64[g]	100	150
9	Opportunity insects	50°C	60°C	64	64	48[c]	48[c]	5[e]	NK[f]	5[e]	NK[f]	64[g]	64[g]	100	150
10–13	Dry wood termites (Species 1–4)	50°C	60°C	64	64	48[c]	48[c]	5[e]	NK[f]	5[e]	NK[f]	64[g]	64[g]	100	150

14	Dry wood termites (West Indian)	50ºC	60ºC	64	64	48[c]	48[c]	5[e]	NK[f]	5[e]	NK[f]	64[g]	64[g]	100	150
15	*Lyctus brunneus*	50ºC	60ºC	64	64	48[c]	48[c]	5[e]	NK[f]	5[e]	NK[f]	64[g]	64[g]	100	150
16	*Xyleborus ferrugineus*	50ºC	60ºC	64	64	48[c]	48[c]	5[e]	NK[f]	5[e]	NK[f]	64[g]	64[g]	100	150
17	*Trogoderma variable*	50ºC	60ºC	64	64	48[c]	48[c]	5[e]	NK[f]	5[e]	NK[f]	64[g]	64[g]	100	150
18	*Trogoderma granarium* (Khapra beetle)	50ºC	60ºC	64	64	80[d]	80[d]	5[e]	NK[f]	5[e]	NK[f]	64[g]	NK[f]	100	150
19	*Hylotrupes bajulus* (European house borer)	50ºC	60ºC	64	64	80[d]	80[d]	5[e]	NK[f]	5[e]	NK[f]	64[g]	NK[f]	100	150
20	Giant African snail	50ºC	60ºC	64	64	128[d]	128[d]	5[e]	NK[f]	5[e]	NK[f]	64[g]	NK[f]	100	150

PES
NKf
NKf
NKf
NKf
NKf

NKf

NKf
NKf
NKf
NKf

NKf

40

OPT: Denotes estimate of the amount of treatment required for quarantine purposes under optimistic assumptions about the effectiveness of the treatment.
PES: Denotes estimate of the amount of treatment required for quarantine purposes under pessimistic assumptions about the the effectiveness of the treatment.
a: Timber is heated from 21ºC to the indicated temperature and kept at that temperature for a specified period. Fields (1992) claims that most insect species will not survive more than 12 hours at 45ºC, 5 minutes at 50ºC, 1 minute at 55ºC and 30 seconds at 60ºC. ISO9000 for softwoods specifies 55 minutes for 5 minutes. In this assessment timber is of 250 mm thickness and it is heated to the specified temperature and kept at that temperature for 22 hours.
b: Current quarantine regulations require heating to this temperature and maintaining the temperature for specified times varying depending on the thickness of timber (for example 6 hours for 50 mm timber; 26 hours for timber thickness of 300mm). In this assessment timber is of 250 mm thickness and it is heated to the specified temperature and kept at that temperature for 22 hours. This regime is assumed to apply whether one uses methyl bromide or some other fumigant under current quarantine rules.
c: Current quarantine requirement assuming that temperatures are above 21ºC. Higher dosages are required for lower temperatures.
d: Current quarantine requirements specify this dose for 48 hours assuming temperatures above 21ºC.
e: This is a dosage for rapid fumigation. However, phosphine is cheaper to use with a pellet generator than with cylinders
f: NK denotes Nil Kill; that is none of the insects die as a result of using this fumigant.
g: Current quarantine requirement assuming that temperatures are above 21ºC. Higher dosages are required for lower temperatures.
h May be excluded from the program in early stages due to lack of penetration.

4.2.1 The impact of new fumigation technologies on timber processing costs

The impacts of fumigant-based replacement technologies on the cost of quarantine treatment of processed timber products from hardwoods are straightforward. The cost change is given by the difference between the cost of treating wood when methyl bromide is used and the cost of treatment when an alternative fumigant is used. The cost of treatment of wood using different fumigants is given in Table 12.

The cost of fumigants is based on the required dose in Table 12 and the prices of fumigants. The information of prices of fumigants is from Desmarchelier (1994b). The wholesale price of methyl bromide is $A300 for 100 kilograms. The wholesale price of phosphine in cylinders is $A354 per kilogram, but it is much cheaper if a pellet generator is used instead of cylinders. The retail price of carbon bisulphide is $A4.96 per kilogram for a 40 litre drum. Methyl isothiocyanate costs about $A5.09 per kilogram. The wholesale price of hydrogen cyanide is $A2444 per tonne.

4.2.2 The impact of the proposed kilning treatment on timber processing costs

Desmarchelier (1994a, 1994b) estimated that the kilning treatment for processed timber products has four main impacts on costs:

- first, there is a cost saving of $A0.54 in heating costs because, under the kilning treatment, it would no longer be necessary to meet the current quarantine requirements to heat processed timber products to 74ºC to disinfest them of insects;
- second, there is the cost for quality control equal to $A0.11 per cubic metre—the costs of control are because of the need to monitor and control temperature. The unit needed for this task is a programmable computer to control and monitor the thermal regime, including remote monitoring through a modem and would cost about $A2000 with a life span of 7 years; and
- third, there is the cost of hygiene estimated as an additional labour cost of $A0.18 per cubic metre to cover the cost of keeping the timber processing establishment clean to avoid re-infestation of treated timber with insects.

Table 13 summarises the costs of the different treatments before and after research. These costs are estimated under the assumption that the price of methyl bromide is likely to remain constant in the short to medium term.

Table 13. Estimate of the cost of fumigants required ($A per unit cubic metres) to disinfest timber of the different insects and the cost of heat ($A per cubic metre) to satisfy quarantine.

No	Cost category	Thermal disinfestation	Fumigant					
		Heat to kill all insects in wood under PN9406[b]	Methyl bromide[d]	Phosphine in cylinders	Phosphine with a pellet generator	Sulfuryl flouride[h]	Carbon bisulphide[i]	Carbonyl sulphide (New)[h]
	Variable costs							
1	Heating costs	$A108.66	$A109.20	$A109.20	$A109.20	$A109.20	$A109.20	$A109.20
2.	Cost of fumigant	$A0.00	$A0.15	$A1.77	$A0.20	na	$A0.75	na
3.	Labour costs	$A1.00	$A1.00	$A1.00	$A1.00	$A1.00	$A1.00	$A1.00
4.	Insurance against the risk of rejection for failing to meet quarantine requirements	$A0.16	$A0.16	$A0.16	$A0.16	$A0.16	$A0.16	$A0.16
5.	Cost of monitoring and temperature control	$A0.11	$A0.00	$A0.00	$A0.00	$A0.00	$A0.00	$A0.00
6.	Cost of hygiene (clean up and keep site clean to avoid re-infestation)	$A0.18	$A0.00	$A0.00	$A0.00	$A0.00	$A0.00	$A0.00
	Total variable costs	**$A110.11**	**$A110.51**	**$A112.13**	**$A110.56**	**na**	**$A111.11**	**na**
	Impact of new technology assuming methyl bromide as the reference technology	$A0.40 (Cost reduction)	$A0.00 (Reference treatment)	$A1.62 (Cost increase)	$A0.05 (Cost increase)	na	$A0.60 (Cost increase)	na

na Cost data on this option was not available at the time this assessment was done.

In section 5 the paper considers a scenario where methyl bromide is banned. In this sensitivity analysis, the 'before research' situation is regarded as the situation with the ban. Banning the use of methyl bromide is likely to disrupt trade in forest products. The 'after research' situation is when trade is restored as a result of discovery of a replacement technology for methyl bromide. This sensitivity analysis attributes the human health benefits to the banning of methyl bromide and assumes that the research project to find replacement technologies for methyl bromide does not have any human health benefits.

4.3 The impacts on the world price and trade dependent price spillovers

The impacts of the proposed technologies summarised in Table 12 are likely to have flow-on effects on the world market price of processed timber products. Prices are likely to change if the kilning treatment works; or if an effective fumigant to replace methyl bromide in the fumigation of processed timber products is found under ACIAR project PN9406.

A single traded commodity, multi-country model developed in Davis and Lubulwa (1994) is used to capture the world-wide impacts on prices of forest products from the proposed technologies.

How different quarantine treatment technologies are likely to change the cost of treating wood for quarantine purposes is shown in Table 13 (second and third last rows of table). By taking these changes in costs, and introducing them in the equations for the equilibrium world prices in Davis and Lubulwa (1994) an estimate of the changes in the world equilibrium prices of processed timber products is obtained. These changes will affect consumers and producers in Malaysia, Papua New Guinea and Australia. However changing the world prices of these forest products will affect producers and consumers in countries that import from the innovating countries—Malaysia, Papua New Guinea and Australia. It will also affect the producers and consumers of these forest products in the countries that are net exporters of the products but are not involved in this research project or unlikely to adopt the results.

The magnitude and direction of the impact on the economic surpluses of producers and consumers in the different countries will depend on a number of factors, including: the size and sign (whether there is an increase or a decrease) of the change in the cost of quarantine treatment of wood as given in Table 13; the relative share of world production and consumption, and the elasticity of supply and demand for processed timber products from hardwoods. In this analysis the elasticity of demand is assumed to be –0.8, while the elasticity of supply is 0.3 (Davis et al. 1989).

Davis and Lubulwa (1994) give the equations for the annual changes in the consumer and producer surplus in the different countries

These benefits are realised only if Malaysia, Papua New Guinea and Australia adopt the quarantine treatment technology that does not cause ozone depletion. The adoption pattern over a 30-year planning horizon is assumed to be:

Time	**Proportion of industry adopting**	**Comment**
1995 to 1997	0	Research period
1998 to 2000	0	Adaptation lag.

2001	0.1	First year that the technology is adopted
2002	0.2	
2003	0.3	
2004	0.4	
20045 to 2024	0.5	Maximum adoption.

Source: Estimate by project scientists

In the first 3 years when the research is developing a non-ozone-depleting quarantine treatment, research costs are incurred at the rate of $A107 000 per annum. In the next 3 year period, it is assumed that the technology is developed into a commercially useable form through adaptive research assumed to cost about $A214 000 per annum. A shorter adaptive research is assumed on the basis that the international trade aspects of the processed timber industry in Malaysia is dominated by a few large private companies some of which plan to participate in the project.

5. SUMMARY AND CONCLUSIONS

5.1 Summary of results for the base case

In addition to the assumptions and parameters already discussed, the base case analysis assumed the following. The price of methyl bromide is not likely to change in the foreseeable future. The adaptive research lag is 3 years, during which additional development costs of $A 214 000 per annum are incurred. A shorter than the usual 8 year adaptive research lag is assumed here. This is because the international trade part of the processed timber products industry in Malaysia is dominated by a few large companies, some of which plan to participate in the project. The additional development costs component is an estimate of the costs required to demonstrate that the scientific results from the project are commercially viable. This component can be the basis of recommended treatments of processed timber products to meet quarantine regulations of countries that trade with Malaysia in these products. One of the sensitivity analyses examines the implications for the economic viability of the project if the development costs are different from those assumed in the base case. The discount rate is 8% per annum; and the planning horizon is 30 years long.

The analysis assumes the whole research effort focuses on one of the options. The internal rate of return and the net present value for the single option chosen are presented.

The paper considers a situation where replacements to methyl bromide are discovered before the use of methyl bromide is prohibited. It is assumed that methyl bromide will be used up to the time that a replacement technology is found. This base case analysis considers two possibilities. Figure 2 graphs the net benefits with and without human health effects. Table 14 summarises the base case results (with and without human health effects) for each of the technological options the project proposes to investigate as potential replacement technologies to quarantine fumigation using methyl bromide.

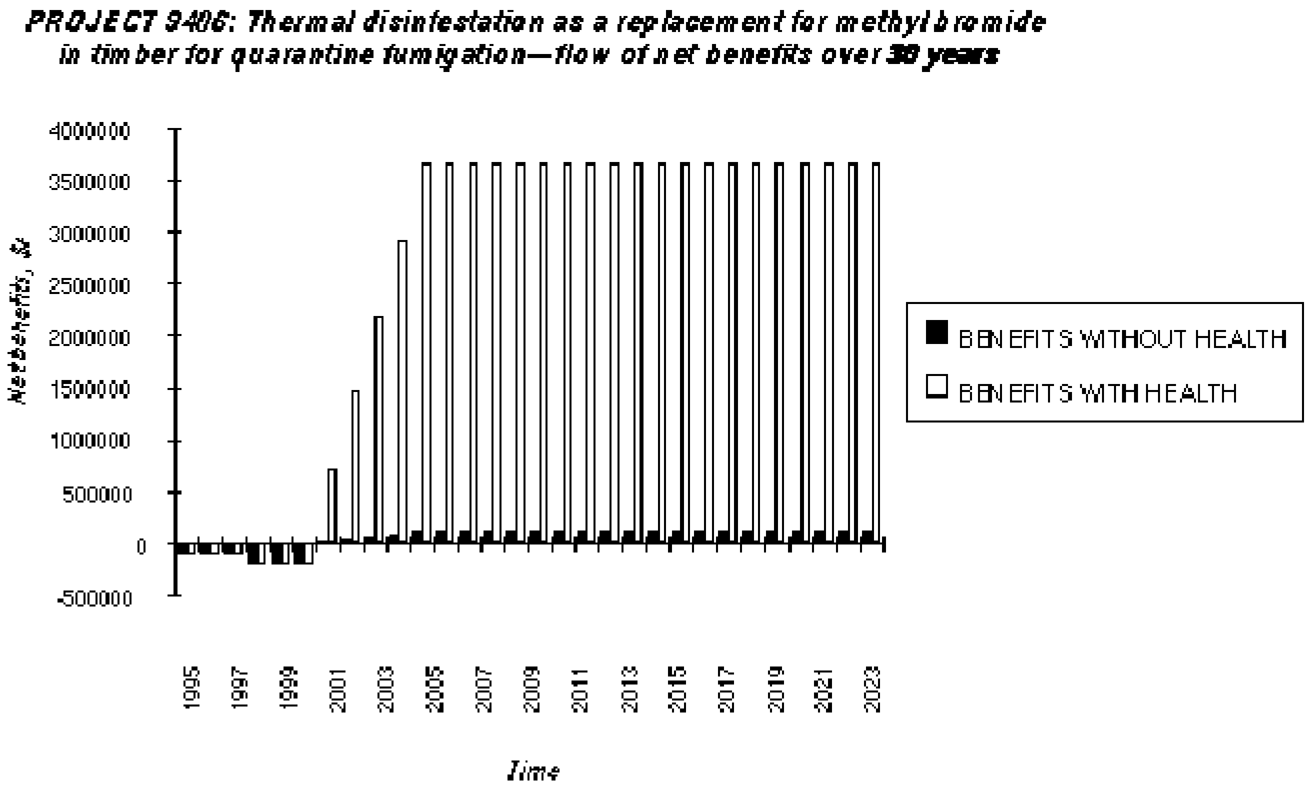

Figure 2. Flow of net benefits from a thermal disinfestation as a replacement for quarantine fumigation.

Table 14. The base case results (with and without human health benefits) of a project development assessment of PN9406: The replacement of methyl bromide in timber for quarantine fumigation where processed timber products are defined to include only sawnwood (non-coniferous) and wood-based panels. The most likely estimate of human health benefits of $A 147.57 m is used.

	Units	Thermal disinfestation	Phosphine in cylinders	Phosphine with a pellets generator	Carbon bisulphide
Change in quarantine costs:	$A/cubic metre	–0.40	1.62	–0.40	0.60
Results without human health benefits					
Total discounted benefits	$Am	0.63	–2.38	0.63	–0.91
Discounted research costs	$Am	0.71	0.71	0.71	0.71
Net present value	$Am	–0.09	–3.10	–0.09	–1.62
Internal rate of return	Percent	7%	Negative	7%	Negative
Results with human health benefits					
Discounted human health benefits	$Am	145.05	145.05	145.05	145.05
Total discounted benefits	$Am	145.68	142.66	145.68	144.14
Discounted research costs	$Am	0.71	0.71	0.71	0.71
Net present value	$Am	144.96	141.95	144.96	143.42
Internal rate of return	Percent	56.97%	53.52%	56.97%	55.26%

In Table 14, for the base case with no human health effects, none of the options are viable. While the thermal disinfestation option has a low, positive internal rate of return of 7% per annum, it is associated with a negative net present value of –$A0.09 million.

The discounted value of human health effects associated with replacement of methyl bromide is about $A145.05 millions. Thus, in Table 14, when human health effects are included, the net present value associated with the thermal disinfestation option increases to $A144 million and the internal rate of return of the thermal disinfestation option increases to 56.9%.

In addition, Table 14 shows that more technological options would have positive internal rates of returns when human health effects are included. When human health impacts are considered, the following options would have positive internal rates of returns:

- thermal disinfestation using a heat treatment, with an internal rate of return of 56.9% per annum;
- phosphine in cylinders yielding an internal rate of return of 53.5% per annum;
- phosphine with pellets, yields an internal rate of return of 56.9% per annum;
- carbon bisulphide has an internal rate of return of 55.3%;
- methyl isothiocyanate has an internal rate of return of 55.9%; and
- hydrogen cyanide has an internal rate of return of 56.3% per annum.

5.2 Distribution of the benefits

Table 15 shows the distribution of the human health benefits by country or region in the analysis. The human health benefits accrue more to the developed countries than to the less developed countries.

Table 15. A summary of a project development assessment of ACIAR PN9406. The replacements for methyl bromide in timber, for quarantine fumigation—with and without human health effects. Processed timber products are defined to include sawnwood (non-coniferous) and wood-based panels. The most likely estimate of global human health benefits is used.

Country or region	PV of producer surplus (PS) $A M,1994	PV of consumer surplus (CS) $A M,1994	Total welfare (PS+CS) Without health $A M,1994	PV of human health benefits $A M,1994	Total welfare (PS+CS) With health $A M,1994	Trade status
BANGLADESH	0.00	0.00	0.00	0.28	0.28	Net importer
CAMBODIA	0.00	0.00	0.00	0.02	0.02	Net exporter
CHINA	–0.01	0.01	0.00	0.51	0.51	Net importer
INDIA	0.00	0.00	0.00	0.12	0.12	Net exporter
INDONESIA	–0.30	0.27	–0.04	0.08	0.05	Net exporter
LAOS	0.00	0.00	0.00	0.00	0.00	Net exporter
MALAYSIA	7.22	–6.36	0.86	0.00	0.86	Net exporter
PAKISTAN	0.00	0.00	0.00	0.01	0.01	Net importer
PHILIPPINES	–0.01	0.01	0.00	0.00	0.00	Net exporter
SRI LANKA	0.00	0.00	0.00	0.00	0.00	Net importer
THAILAND	0.00	0.00	0.00	0.02	0.02	Net importer
VIETNAM	0.00	0.00	0.00	0.01	0.01	Non-trader

JAPAN	0.00	0.00	0.00	24.97	24.96	Net importer
REST OF ASIA	–0.10	0.08	–0.02	0.06	0.04	Net importer
AUSTRALIA	–0.06	0.04	–0.01	1.96	1.95	Net importer
NEW ZEALAND	–0.01	0.01	0.00	0.11	0.11	Net exporter
PAPUA NEW GUINEA	0.01	0.00	0.00	0.01	0.01	Net exporter
FIJI	0.00	0.00	0.00	0.00	0.00	Net exporter
REST OF OCEANIA	0.00	0.00	0.00	0.00	0.00	Net importer
EUROPE	–0.44	0.31	–0.13	65.35	65.22	Net importer
NORTH & CENTRAL AMERICA	–0.27	0.25	–0.03	41.30	41.27	Net exporter
SOUTH AMERICA	–0.06	0.06	0.00	3.32	3.32	Net exporter
FORMER USSR	–0.04	0.04	0.00	6.76	6.76	Net importer
AFRICA	–0.03	0.02	–0.01	0.14	0.13	Net importer
TOTAL DISCOUNTED BENEFITS			0.63	145.05	145.68	
TOTAL DISCOUNTED COSTS			0.71	not applicable	0.71	
NET PRESENT VALUE			–0.09	not applicable	144.96	
INTERNAL RATE OF RETURN			7%	not applicable	57%	

The main explanation for this is that ultraviolet radiation-induced diseases are more common in societies where life expectancy is longer and gross domestic products are higher. In Bryant et al. (1992), the highest incidence for all these diseases were among the elderly. In this paper value of life is related to productive capacity lost or production lost as a result of premature death. Thus, in countries where individuals die earlier from other diseases, the benefits from reduced incidence of ultraviolet radiation-induced diseases are reduced. Similarly, poorer countries tend to have lower gross domestic product figures and this tends to reduce the unit costs of fatalities.

Table 15 shows the distribution of potential consumer and producer surplus from a change in technology that could result from the project. If thermal disinfestation is adopted, Table 15 then suggests the following:

- Producers in Malaysia and Papua New Guinea the countries that are the overseas collaborators in the research that yields a technology to replace methyl bromide are likely to gain. If the technology works, these countries gain because thermal disinfestation as a technology for quarantine treatments is cheaper than current practice. Thus the innovating countries, benefit from a reduction from their transport to world markets. Australia is a net importer of processed timber products. Producers in Australia lose a little but their loss is more than offset by the gain to consumers in Australia.
- Apart from consumers in Malaysia, all consumers in the world are not likely to lose from this research project.

Table 15 is based on the heat disinfestation technology, however similar results are associated with other cost reducing technologies.

5.3 Sensitivity analyses

In this section an analysis of the sensitivity of the research benefits to variations in the following parameters is done:

- the human health impacts (Table 11);
- the quantity of processed timber products from hardwood; and
- the cost of adaptation of the new quarantine treatment technology.

5.3.1 Human health benefits

In the base case analysis, the most likely estimates of human health benefits are used in estimating the internal rates of return and the net present values of the different options. Table 11 gives a low and a high human health benefit estimate.

In estimating the human health benefit from a reduction in the use methyl bromide for quarantine fumigation of timber this paper considers three possible cases:

- the low human health benefit case;
- the most likely human health benefit case; and
- the high human health benefit case.

The low human health benefit case

This case takes the sceptic's view that the concern about ozone depletion and its effects on human health may be an exaggeration. For example this is the view expressed by Professor F. Singer (see Pearce, 1994) who argues that:

> 'The main device used by researchers to measure ozone levels in the upper atmosphere confuses the gas with another pollutant, sulphur dioxide. What we may really be seeing is a fall in the amount of sulphur dioxide in the air, not ozone'.

The low human health benefit case in this paper assumes that there may be some credence to the literature that argues that ozone depletion occurs and that it may have negative human health impacts. However, it is assumed that the share of methyl bromide in the global anthropogenic depletion of the ozone layer is a hundredth of the value assumed by Bryant et al. (1992).

The most likely human health benefit case

The assumptions spelt out in Table 6 to Table 10 represent the most likely set of assumptions about incidence and cost of disease induced by or related to the use of methyl bromide.

The high human health benefit case

In this case the unit costs of disease for a person suffering from a non-fatal medical condition is assumed to be equal to the unit cost in Australia. This gives an estimate of the human health benefit on the high end of possible human health benefit estimates. Table 11 summarises the estimates of the human health benefits under the three sets of assumptions.

If the human health benefits are no more than the low human health benefit estimate then inclusion of human health effects does not significantly change the viability of different options. Under the assumption of low human health benefit only thermal disinfestation is a viable option which is the conclusion from an analysis without human health benefits. At the other extreme, when the high estimate of human health benefits is assumed, then all options are viable and have positive internal rates of returns.

This assessment raises one important question though, and this is demonstrated in Table 15. From Table 15 it is seen that most of the human health benefits accrue to regions of the world which are not part of ACIAR's mandate. The question is whether ACIAR should fund the project in full or whether some other funding body, from the regions that are likely to benefit most from a non-ozone depleting technology, should share in the costs of the project ?

5.3.2 The quantity of processed timber products from hardwood

The focus of the project is on a methyl bromide replacement treatment for quarantine fumigation of processed timber products from hardwoods. The appropriate output data should be processed timber products from non-coniferous trees. However in the base case, processed timber products are defined as comprising :

- sawnwood (non-coniferous); and
- wood based panels (non-specific).

It is likely that wood based panels include products from both non-coniferous and coniferous products and would lead to an over-estimation of benefits by the inclusion of products for which the technology developed is not applicable. A sensitivity analysis was done in which it was assumed the technology developed in the project would only be applicable to sawnwood (non-coniferous).

The impact of using only sawnwood (non-coniferous) in the analysis is that the internal rates of return and the net present-values are marginally reduced for all options in the base case without human health benefits, as would be expected. However, when human health benefits are considered the internal rates of return of different options are very close to those obtained when processed timber products include both sawnwood and wood-based panels. This is due to the magnitude of the human health benefits relative to the non-health-benefits of the project.

5.3.3 The costs of adaptive research

In the base case, it is assumed that an additional adaptation-research expenditure of $214 000 per annum is incurred for a period of 3 years before a thermal disinfestation regime or an alternative fumigant to methyl bromide is accepted and adopted for quarantine purposes. In the sensitivity analysis, it is assumed that these annual adaptation research costs are half those in the base case. The internal rates of return for all options are higher under this set of assumptions than under the base case.

5.4 Conclusions

Methyl bromide has been named as an ozone depleting chemical and there is a risk that it may be banned in the near future.

This paper has described a project development assessment of ACIAR project number 9406 which proposes to examine a variety of possible replacement technologies for quarantine fumigation using methyl bromide.

If this project does not proceed and methyl bromide is banned, it is estimated that there are likely to be net welfare losses ranging from –$A 200 millions if the elasticities of demand and supply for processed timber products are low. However if the elasticities are high then the welfare losses due to disrupted trade could be as high as –$A 1186 million over a 30 year time horizon. Since banning of the use methyl bromide is likely to lead to human health benefits of about $A 145millions, the net welfare losses of banning methyl bromide could range from –$A 55 millions to –$A 1041 millions.

This assessment included the following impacts of a technology to replace methyl bromide:

- the human health benefit from reducing the incidence of ultraviolet radiation B-induced medical conditions;
- the impact on the cost of quarantine treatment of timber in the countries collaborating in the research project, namely, Malaysia, Papua New Guinea and Australia; and
- the impacts on the world price of processed timber products from hardwoods and the trade-dependent price spillovers to other countries and regions in the world.

The most likely estimates ($A145 million) of global human health benefits from the replacement of methyl bromide with a non-ozone depleting technology are based on parameter values from a detailed study, by the National Health and Medical Research Council (1989), of the health effects of ozone layer depletion. The estimate of human health benefits from a reduction in ozone-layer depletion could be as low as $A0.63 million globally if a sceptic's view about the importance of ozone-depletion is taken. On the other hand human health benefits could be as high as $A211 million if the unit costs of non-fatal medical conditions are assumed to equal the unit costs of these conditions in Australia.

The heat treatment proposed in the project seems to be a viable proposition. This option is estimated to have an internal rate of return of 7% and a net present value of $A 0.09 if the human health effects are left out. However, when human health effects are included, the internal rate of return rises to 56.9% and the net present value increase to $A144.9 million.

This paper shows that its possible to incorporate atmospheric environmental degradation impacts in research evaluation.

1 Commonwealth Scientific and Industrial Research Organisation and and Forest Research Institute of Malaysia.

2 Papua New Guinea is not a formal collaborator in the project. However, the multinational companies that control the harvesting processing and international marketing of processed timber products in PNG are largely Malaysian based companies.

4 The need for simple indices to compare the stratospheric impact of one halocarbon against others as a scientific guide to public policy has led to the development of the concept of the ozone depletion potential (ODP). This represents the amount of ozone destroyed by the emission of one kilogram of a chosen gas over a particular time scale, as compared to one kilogram of a reference molecule, usually CFC-11. The values used in the Montreal Protocol reflect the chronic ozone impacts of methyl bromide over infinite time scales – i.e. steady state (UNEP, 1992a).

5 For example estimates of the ODP of methyl bromide against time yield the following results: If the time horizon is 5 years, the ODP is 20; if the time horizon is 10 years, the ODP is 7; if the time horizon is 15 years, the ODP is 4, if the time horizon is 30 years, the ODP is 1.9 (UNEP, 1992a).

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APPENDIX A

DECLARATION ON METHYL BROMIDE

DECLARATION BY AUSTRIA, BELGIUM, DENMARK, FINLAND, GERMANY, ICELAND, ISRAEL, ITALY, LIECHTENSTEIN, NETHERLANDS, SWEDEN, SWITZERLAND, UNITED KINGDOM, UNITED STATES AND ZIMBABWE.

The above parties present at the fifth meeting of the Parties to the Montreal Protocol,

- Concerned about the continuing depletion of the ozone layer of both the northern and southern hemispheres, partly due to methyl bromide,
- Being aware that reductions in the emissions of methyl bromide will have a beneficial effect on the ozone layer, especially in the coming 10 years where chlorine concentrations in the atmosphere will reach a critical maximum,
- Being also aware that in many cases more environmentally sound alternative substances, methods and technologies are already available and others are rapidly being developed,
- Stress the need to strengthen the control measures decided at the Fourth Meeting of the Parties to the Protocol,
- Declare their firm determination to reduce their consumption of methyl bromide by at least 25% at the latest by the year 2000, and to phase out totally the consumption of methyl bromide as soon as technically possible.

Bangkok, 17–19 November 1993.

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