Articles

Market Failure and Chemical Use

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The objective of this paper is to develop a cost-benefit model that presents an analysis of the costs of implementing safe agrichemical practices, being the use of recommended protective equipment, and the benefits derived from these practices, being the reduced risk of consequent health problems.

Initially, the cost-benefit analysis relies on surveys of the prevalence of short term acute cases of agrichemical poisoning among farmers and farm workers (inclusively termed farmers in the study), and epidemiological research on the elevated risks of cancer for farmers. The increased risks of health problems due to agrichemical exposure is then valued, using as a reference the literature on the willingness to pay for preventative action.

1. Introduction

Although a majority of farmers believe that the safe management and use of agrichemicals is an important issue for most producers in the primary sector (Gray), there is evidence that a considerable segment of farmers are not using adequate protective equipment (Pryde; Houghton and Wilson; Scully, Brush and Sheppard; McMullen *et al.;* Kondinin Group). Table 1 presents the findings of these three New Zealand and two Australian studies of agrichemical users and their protective equipment use.[1]

Generally for farmers, the normal protection from exposure to agrichemicals is through the use of protective equipment (BAEA; Scully, Brush and Sheppard). Freed *et al.;* Pryde; Davies; and Cantor *et al.,* have all found statistically significant differences in farmer exposure to agrichemicals and consequent health problems when measured on the basis of use/non-use of recommended protective equipment. Pryde in his study of New Zealand farmers found those respondents not wearing any protective equipment had an approximately six times greater risk of suffering acute agrichemical related health problems than those farmers using some form of protective equipment. Cantor *et al.,* has also found that those farmers who did not use protective equipment, as compared to the entire exposed group, had a significantly higher risk of developing non-Hodgkins lymphoma. Burgess has also stated that "there is good evidence that pesticides handled correctly pose no threat to health" (pp.58).

2. Risk

Two separate classes of agrichemical poisoning risks to human health are commonly referred to in the literature studying the effects of chemical exposure (WHO). These are the acute and long-term chronic health risks.

Acute health risks are defined as the probability of agrichemical poisoning that results from short term exposure. Acute agrichemical poisoning generally occurs in the event of an accident or because of bad working practices. The outcome of the acute short term exposure occurs soon after the exposure event.

Chronic poisoning health risks occur as a result of small repeated doses of an agrichemical over a long

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[1] One referee has recommended that the Pryde and Houghton and Wilson studies did not focus on agrichemical protective equipment use and that these studies asked a number of general questions which happened to include questions on chemical use. Scully, Brush and Sheppard examined protective equipment use as part of a wider study into New Zealand agrichemical users attitudes, opinions and behaviour. McMullen *et al.,* investigated non-growers protective equipment use as part of a wider study of pesticide exposure in central, south-east and south-west New South Wales. The findings from Kondinin Group are derived from a national agricultural survey.

Table 1: Farmers' Use of Chemical Protective Equipment

Protective Equipment Use by Body Part Protected[a] (%)	Pryde (1981)	Houghton and Wilson (1992)[b]	Scully, Brush and Sheppard (1993)	McMullen et al. (1993)	Kondinin Group (1993)
No Protection[c]	42.3	28.0	36.7	-	-
Head	-	-	-	89.5	-
Face/Head/Neck	24.6	26.1	25.7	-	-
Eye Protection	-	13.7	3.5	34.9	9.0
Upper Trunk	16.4	44.1	-	24.4	-
Lungs	-	28.6	-	-	15.5
Full Overalls	-	-	47.0	43.0	27.0
Arms and Hands	42.0	41.6	-	-	-
Lower Trunk	15.3	44.7	-	41.9	-
Legs and Feet	17.8	49.7	-	-	-
Feet	-	-	20.3	97.7	17.5

a Scully, Brush and Sheppard (1993), McMullen *et al.* (1993) and Kondinin Group (1993) considered the use of specific forms of protective equipment, rather than protection of specific body areas as surveyed in the earlier studies by Pryde (1981) and Houghton and Wilson (1992).

b Only respondents in the sample who considered their health had been affected by agrichemicals, in the previous 12 month period, were surveyed on their protective equipment use.

c An additional 48.4 per cent of respondents in the Pryde (1981) survey stated that they did not consistently wear protective equipment when handling agrichemicals.

period of time. Unlike acute poisoning, which generally causes rapidly developing and easily recognised symptoms, symptoms of chronic poisoning may not become evident for up to 30 years.[2] When the symptoms finally develop, they may not be recognised as having been caused by exposure to an agrichemical months or years in the past (Stimmann).

Two surveys have investigated acute agrichemical poisoning incidence in New Zealand agriculture (Pryde; Houghton and Wilson). These two studies found that 4.4 per cent and 8 per cent of farmers respectively, indicated that their health had been affected by agrichemical usage over the preceding twelve month period. In the Kondinin Group survey, 36 per cent of Australian farm chemical users indicated that at some stage they had suffered ill effects from using agricultural products. Further, McMullen *et al.,* in their study of non-growers in New South Wales found that 85.7 per cent stated they had experienced chemical exposure at some time, and felt that it had affected their health. However, although results from these studies indicate a significant and increasing incidence of acute agrichemical poisonings, the results could actually underestimate the true incidence of acute agrichemical poisonings. The underestimate may have occurred as the surveys asked respondents to make a non-professional subjective statement about the causal connection between agrichemical use and health impairment.

There is also increasing evidence that long term chronic exposure of farmers to agrichemicals may not produce accompanying acute symptoms (Sharp *et al.*). In addition, Schramm and Teichmann indicate that it is impossible to determine a minimum exposure level for a chemical carcinogen below which level there is no carcinogenic risk .

Many methods and study populations have been used to investigate the relationship, and subsequent risk, between agrichemical exposure and cancer. However, three general lines of research have dominated the inquiry into the carcinogenicity of agrichemicals (Sharp *et al.*). One such line of research studies farming occupations as an indirect, albeit consistent, line of inquiry into the carcinogenicity of agrichemicals. A second line of inquiry has been the study of pest control operators and cohorts of workers with known exposure to agrichemicals. Generally, these studies do not address the effects of specific agriche-

2 The latency period for the chemical induction of solid malignant tumours in man is generally considered to be in the range of 10-30 years (Smith *et al.*; Sharp *et al.*).

micals but attempt to show an associative relationship between some type of agrichemical exposure and a cancer outcome. The third body of literature attempts to assess the risk of cancer from specific agrichemicals, notably phenoxy herbicides and related compounds, organochlorides, and DDT.

Table 2 presents a summary of selected epidemiological studies that have investigated the relationship between occupational agrichemical exposure and cancer mortality. Table 2 outlines the source of the research, the geographic location, the study period and number

Table 2: Selected Studies into the Delayed Health Hazards of Agrichemical Exposure

Source	Region	Study Period (sample size)	Activity	Outcome	OR/ SMR
Fasal, Jackson and Klauber (1968)	California	1959-61 (1,882)	Farming	Leukaemia	1.14
Milham (1971)	Oregon/ Washington	1950-67 (327)	Farming Horticulture	Leukaemia	1.26 2.3
Blair and Thomas (1979)	Nebraska	1957-74 (1,084)	Farming	Leukaemia	1.25
Wang and MacMahon (1979)	United States	1967-76 (16,126)	Agrichemical Applicators	Lung Cancer	1.15
Barthel (1981)	East Germany	1948-72 (1,648)	Farming	Lung Cancer	2.0
Eriksson *et al.* (1981)	Sweden	1974-8 (38)	Phenoxy Acid Exposure	Soft Tissue Sarcoma	6.8
Burmeister (1981)	Iowa	1971-78 (133)	Farming	Multiple Myeloma	1.27
Burmeister, Van Lier and Isacson (1982)	Iowa	1964-78 (5,025)	Farming	Leukaemia	1.24
Smith *et al.* (1982)	New Zealand	1976-80 (102)	Farming	Soft Tissue Sarcoma	1.45
Cantor (1982)	Wisconsin	1968-76 (774)	Farming High Insecticide Use High Herbicide Use	Non-Hodgkins Lymphoma	1.7 2.4 2.1
Blair *et al.* (1983)	Florida	1965-77 (3,827)	Licensed Agrichemical Applicators	Lung Cancer	1.35
Burmeister *et al.* (1983)	Iowa	1964-78 (1,651)	Farming	Multiple Myeloma Non-Hodgkins Lymphoma	1.48 1.26
Buesching and Wollstadt (1984)	Northwestern Illinois	1973-80 (71)	Farming	Non-Hodgkins Lymphoma	2.65
Balarajan and Acheson (1984)	England/ Wales	1968-76 (52)	Farming	Soft Tissue Sarcoma	1.7
Cantor and Blair (1984)	Wisconsin	1968-76 (411)	Farming	Multiple Myeloma	1.4
Delzell and Grufferman (1985)	North Carolina	1976-78 (47)	Farming	Non-Hodgkins Lymphoma	1.0
Pearce, Smith and Fisher (1985)	New Zealand	1977-81 (734)	Farming Horticulture	Multiple Myeloma Non-Hodgkins Lymphoma Malignant Lymphoma/ Multiple Myeloma	2.22 1.76 5.51
Musicco *et al.* (1988)	Italy	1983-4 (240)	Farming	Brain Cancer	1.6
Cantor *et al.* (1992)	Iowa/Minnesota	1980-83 (622)	Farming	Non-Hodgkins Lymphoma	1.2
Smith and Christophers (1992)	Victoria, Australia	1982-88	Phenoxy Herbicide and Chlorophenol Exposure	Soft Tissue Sarcoma Malignant Lymphoma	2.0 2.7

of diseased,[3] the study population characteristics, and the type of cancer for which an associative link to agrichemical exposure was investigated. The relative risks (or relative odds) are presented for the case-control studies. The strength of an association in a case-control study may be expressed in terms of the relative risk (risk ratio or odds ratio (OR)). In occupational epidemiology the relative risk is the most common measure of a risk related to a compound. The standardised mortality rate (SMR) findings are also presented for the cohort studies (Wang and MacMahon; Blair *et al.,* 1983). The SMR is the ratio between the observed number of events, generally the cohort's incidence of cancer mortality derived from death certificate analysis, which is assumed to be Poisson distributed, and the expected number of events, generally the cancer mortality rate among non-cohort subjects, which is assumed to be fixed.

The Fasal, Jackson and Klauber study results presented in Table 2 is one of the first inquiries into the effects of long term chronic agrichemical exposure to investigate cancer mortality and agricultural occupation. They found that although mortality from all cancer was significantly reduced in farm residents, as contrasted to a control group of non-farm workers, leukaemia mortality was significantly higher among farm residents. An increased leukaemia mortality rate among farmers from chronic agrichemical exposure has also become one of the most consistent findings in later studies (Milham; Blair and Thomas; Burmeister, Van Lier and Isacson).

Clarke has stated that "No national or state data are available currently to detail the nature and extent of the pesticide exposure problem for those involved in agriculture in Australia" (pp.30). However, in their limited case-control study of 82 male Victorian patients with soft tissue sarcoma or malignant lymphoma, Smith and Christophers did find that for those subjects who had experienced exposure to phenoxy herbicides or chlorophenols for a period of more than 30 days the estimated relative risks were 2.0 for soft tissue sarcoma and 2.7 for malignant lymphoma.

Pearce, Smith and Fisher (1985) in a study of New Zealand farmers and horticulturalists, found the case group displayed a higher cancer mortality rate in the occupational category involving agriculture and forestry (SMR= 1.25). This excess was almost entirely among those aged less than 65 years at time of registration (SMR = 1.45), particularly among patients with multiple myeloma (SMR =2.22), and the category including nodular lymphoma, mycosis, fungoides and unspecified non-Hodgkins lymphoma (SMR =1.76).

The New Zealand findings on the chronic effects of agrichemical exposure add to the growing body of evidence that indicates farmers are at an increased risk of developing non-Hodgkins lymphoma (Burmeister *et al.,* Bueschlng and Wollstadt) and multiple myeloma[4] (Burmeister; Cantor and Blair). Musicco *et al.,* also found farmers face an increased risk of developing brain cancer. The observed risk ratio's however were not large, but the use of relatively crude exposure information, such as is found on cancer registration certificates, tends to bias the observed excess risk toward the null value (Copeland *et al.*). Hence, the true risk to farmers is likely, if anything, to be larger than the data suggest.

3. The Valuation of Risk Reduction

In making decisions about valuing acute and chronic agrichemical risks at an individual level, and whether 'safe' agrichemical practices should be implemented, an analysis is required of the benefits of safety and the costs of achieving safety. The optimum level of safety will be achieved when the risks have been reduced to the point where the cost of any extra reduction just equals the benefits, ie. risks should be reduced until the 'marginal cost equals the marginal benefit.[5]

An analysis of the cost-benefit implications of agrichemical practices therefore requires that a monetary value is placed on the benefits of safe agrichemical practices. If this is not done, then the financial resources allocated to the risk reduction strategy, in this case agrichemical safety equipment, may be inefficient. The relevant questions become how much people will pay for a reduction in their chance of premature death?, or how much compensation they would require to accept a higher risk? If such explicit monetary valuations of the benefits of reduced risk are to be used in cost-benefit approaches to decision

[3] The number of cases sampled for the selected cancers for the case-control studies, and the number of exposed subjects in the cohort studies, are given in parentheses.

[4] Cancer of the bone marrow.

[5] The relevant question is 'Is agrichemical application safe enough?' This involves an analysis of the level of risk acceptable to the farmer in terms of the costs of protection and the benefits from being protected. This level of acceptable risk does not necessarily imply zero risk.

making, a method of calculating the required valuation is necessary. The following two subsections consider the valuation of mortality and then examine the valuation of non-fatal injury.

3.1 Valuation of Mortality

Several methodologies have been proposed for generating estimates of the value of reducing the risks of death, however, the current consensus in the economics profession is that the appropriate way to measure mortality value is to determine what people are willing to pay to save a life (Fisher, Chestnut and Violette). Willingness to pay (WTP) estimation studies can be grouped into three categories: wage-risk studies, consumer market studies and contingent valuation studies.

Wage-risk studies estimate the wage premium associated with greater risks of death on the job, while consumer market studies examine the observable trade-offs people make between risks and benefits in their consumption decisions. In general however, the contingent valuation methodology is favoured as the preferred approach to statistical life valuation, and is considered to provide estimates that are a reliable indication of the order of magnitude of the 'true life value' (Jones-Lee, Hammerton and Phillips). In comparison, the contingent valuation approach poses respondents with a hypothetical market situation to survey their WTP for alternative levels of safety.

In contingent valuation studies the 'value of a statistical life' is computed by surveying what people will pay on average (\$n), to reduce their probability of death per year by x^{-1} (where x^{-1} is very small). The assumption is that a group of x people, would together, be willing to pay \$x.n to avoid one expected death. Therefore in these studies a calculated \$x.n is the 'value of a statistical life' (Marin).

The most recent and comprehensive contingent valuation study that investigated values of New Zealand statistical life, was a study by the Land Transport Division (Miller and Guria). Five willingness to pay questions yielded average values of a statistical life from \$NZ2.15 million to \$NZ3.44 million, with an overall average of \$NZ2.84 million.[6] This study determined that the recommended New Zealand 'statistical life' value is at the low end of the range of fifty reliable international willingness to pay estimation studies, where 'statistical life' valuations ranged from \$2.25 to \$9 million (Maier, Gerking and Weiss; Miller). These studies include estimates from Australia, Austria, Canada, Sweden, Taiwan, the United States and the United Kingdom. The majority of these studies use the consumer market study methodology and provide calculated values that are consistent with the values obtained from contingent valuation surveys (Rice *et al.* 1989, Miller 1990).

3.2 Valuation of Non-Fatal Injury

WTP may also be used to value non-fatal injury. However considerably less research has been undertaken to elicit the valuation of non-fatal injury or illness risk reduction, partly because fatal injuries generally constitute the 'worst case', and partly because death is clear-cut and statistically easy to measure.

Moore and Viscusi in a US study have however made calculations of the WTP to avoid a non-fatal injury that was severe enough to involve time off work. From this study the valuation of a non-fatal injury (which was severe enough to involve days of work) was less than 0.5 per cent of the value of a fatal injury. Although non-fatal injury valuations are not as reliable as the value of life estimates, the range of non-fatal injury valuations, calculated by Moore and Viscusi, are consistent with those values found elsewhere in the literature (Viscusi). Other US studies have determined similar percentages, of 1 per cent or less, for non-fatal as compared to fatal injuries (Marin). Applying a non-fatal injury valuation of 0.5 per cent to Miller and Guria's New Zealand 'statistical life' valuation would result in a non-fatal injury valuation of \$14,200.

4. Model

4.1 Theoretical Model

The following factors will have an effect on any cost-benefit determination of the health risks to farmers from acute and chronic agrichemical exposure, and the value of potential risk reduction strategies.[7]

[6] Unless otherwise stated monetary values are reported in September 1994 New Zealand dollars. The New Zealand long term inflation rate (GNP Deflator) is used as the adjustment factor. The interest rate figure equals the unweighted average yield to maturity of ten issues with 10 years or more to maturity. Data comes from various issues of International Financial Statistics headed "Government Stock" published by the International Monetary Fund, Washington.

[7] New Zealand data is used in this study as it has been stated by Clarke that "There is inadequate information available to define the degree or nature of risk to those handling or associated with pesticide use in agriculture in Australia" (pp.30).

- The acute agrichemical poisoning risk.
- The farming-related cancer mortality risk.
- The WTP for risk reduction.
- Agrichemical exposure duration.
- The cost of risk reduction.

Benefits are measured as the saved costs of increased life expectancy. Costs are measured as the costs of lifetime prevention by good practice (i.e. wearing protective clothing).

4.1.1 The Acute Agrichemical Poisoning Risk

For the purposes of this analysis the acute health risks are derived from surveys of illness and injury experience among farmers and farm workers that investigated the extent of self-reported cases of minor agrichemical poisoning.

The most recent survey of agrichemical illness and injury experience among farmers (Houghton and Wilson) indicated that 8 per cent of sampled farmers thought their health had been affected by chemicals used on their property over the period April 1991 to March 1992. However, only 25 per cent of the 8 per cent of affected respondents (2 per cent) indicated they were unable to continue their normal work routine. Therefore the 2 per cent estimate is the correct one to use as the lack of published research into non-fatal injury valuation means only the valuation of injuries or illnesses that are severe enough to involve days off work can be calculated. The model used in this study does not explicitly value the 6 per cent risk of acute agrichemical poisoning, incurred by farmers from occupational agrichemical exposure, that did not result in time off work. Such a specification will necessarily underestimate farmers WTP for avoidance of acute agrichemical poisoning risk.

4.1.2 The Farming-Related Cancer Mortality Risk

The chronic health risks from agrichemical exposure are derived from epidemiological research that has investigated cancer mortality risks for farmers. Exposure to agrichemicals, particularly phenoxy acid herbicides, have been linked to non-Hodgkin's lymphoma (Cantor; Burmeister *et al.* 1983; Pearce, Smith and Fisher 1985) and soft tissue sarcoma (Eriksson *et al.,* Smith *et al.* 1982, Balarajan and Acheson), although risk estimates vary widely among studies, and in some the risk was not increased at all (Pearce and Reif 1990). Insecticides have also been associated with leukaemia (Fasal, Jackson and Klauber; Burmeister *et al.* 1983), multiple myeloma (Cantor and Blair 1984, Pearce, Smith and Fisher 1985), and brain cancer (Musicco *et al.*).

In order to develop a model for assessing farmers' health risks from agrichemical exposure, the findings from Blair *et al.'s* (1992) comprehensive meta analysis of cancer risks among farmers is used to derive the cost of chronic long term exposure to agrichemicals. Their article which summarised cancer risks among farmers, included data from broad occupational surveys on cancer mortality or morbidity assembled from several countries including New Zealand. They included published surveys which provided data on many occupations or many diseases, or both, to avoid the potential problem of a bias toward the reporting of positive findings. The article specifically excluded studies of individual cancers in which negative findings were likely to go unreported. In their meta-analysis they summed the observed and expected numbers for specific cancers among farmers to create meta-relative risk (MRR) estimates to minimise the influence of unusual chance findings from individual studies on the overall interpretation.[8]

Table 3 presents a summary of the Blair *et al.* (1992) findings for cancer types that have been specifically associated with agrichemical exposure.[9] Table 3 outlines the nature of the disease, the total sampled number diseased, the meta relative risk, and the number of studies that were reviewed.

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[8] This procedure weights the contribution of each study by its size.

[9] The incidence of soft tissue sarcomas has also been linked to exposure to agrichemicals (Smith *et al.*; Balarajan and Acheson;), however the meta-analysis by Blair *et al.* (1992), which is the source for the relative risk estimates used in this model, did not analyse the MRR for soft tissue sarcomas among farmers. A measure for the increased risk of the incidence of soft tissue sarcoma due to occupational agrichemical exposure is therefore not included in this study. In New Zealand in 1992 soft tissue sarcoma was the cause of 15 male deaths.

Further, although Barthel and Blair *et al.* (1983) have found agrichemical users face an increased risk of developing lung cancer, Blair *et al.'s* (1992) meta-analysis of the epidemiological literature that has investigated farmers and lung cancer risks indicated that the risk to farmers in developing lung cancer is not elevated from the general population. The general epidemiological finding of low rates of cancer of the lung, for farmers, may be explained by the low prevalence of smoking observed globally among farmers (Donna *et al.*). This hypothesis could explain the significant finding in the Barthel study, as the smoking habits of Barthel's exposed subjects did not differ from those of the general male population in the German Democratic Republic.

Table 3: Summary of Mortality Risks

Disease	Total Diseased	Meta Relative Risk	Number of Studies
Brain	979	1.05	18
Non-Hodgkins Lymphoma	911	1.05	14
Multiple Myeloma	694	1.12	12
Leukaemia	2,625	1.07	23

For the selected cancers that have been linked to agrichemical exposure, the MRR estimates are not large. The reviewed studies indicate that the average increased relative risk for farmers for the selected agrichemical exposure related cancers was between 5 and 12 per cent. The authors note that it is perhaps not surprising that the relative risks from these summary measures were small because the broad occupational category of farmer was all that was available for these analyses. Since not all farmers have the same exposures, combining those with different exposures would tend to dilute the effects of relevant exposures and bias risk estimates toward the null hypothesis (Checkoway, Pearce and Crawford-Brown). Blair *et al.* (1992) highlight the potential magnitude of such a dilution effect by referring to data from a recent study in Iowa and Minnesota (Brown *et al.* 1990). Among the 698 population-based referents who ever lived on farms, 110 (16 per cent) never used insecticides and 344 (49 per cent) never used herbicides. The proportion of farmers who used specific classes of agrichemicals was even smaller. Approximately 40 per cent of the farmers used phenoxy acid herbicides and 20 per cent used organochloride insecticides, the two most frequently used agrichemical classes. Even if these chemicals were strong risk factors for a particular cancer, analyses based simply on the occupational title of the farmer could seriously underestimate the relative risks. As Blair *et al.* (1992) note, classifying farmers by specific exposures is clearly preferable, but such a classification was not available from the surveys included in their review.

In 1992 approximately 26 per cent of all deaths in New Zealand were attributed to cancer (New Zealand Health Information Service). Table 4 presents the cancer mortality statistics for the selected cancers for New Zealand males in 1992. The disease type, number of deaths, and mortality rate per 100 000 of population at the ages given, are presented for males by age grouping. Cancers that have been linked to agrichemical exposure, namely brain cancer, non-Hodgkins lymphoma, leukaemia and multiple myeloma, accounted for 449 male deaths in New Zealand in 1992.[10]

[10] This figure is derived from Mortality and Demographic Data, 1992, published by the New Zealand Health Information Service. Causes of death included in the mortality figure, and the subsequent analysis, include brain cancer (malignant neoplasm of the brain, ICD 191), non-Hodgkins lymphoma (lymphosarcoma and reticulosarcoma, ICD 200; other malignant neoplasm of lymphoid and histiocytic tissue, ICD 202), multiple myeloma (multiple myeloma and immunoproliferative neoplasms, ICD 203), and leukaemia (lymphoid leukaemia, ICD 204; myeloid leukaemia, ICD 205; monocytic leukaemia, ICD 206; other specified leukaemia, ICD 207). ICD refers to the International Classification of Diseases numbers.

Table 4: Cancer Mortality for Selected Cancer Types, 1992

Disease	Cancer Mortality Rates for NZ Males over 20, by Age Group[d]										
	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74
Brain Cancer	1	3	5	6	6	8	10	10	19	12	9
	(0.72)	(2.32)	(3.66)	(4.81)	(5.03)	(8)	(11.86)	(14.42)	(27.20)	(19.58)	(19.88)
Non-Hodgkins	1	2	2	2	6	4	6	10	8	24	20
Lymphoma	(0.72)	(1.55)	(1.46)	(1.60)	(5.03)	(4)	(7.12)	(14.42)	(11.45)	(39.16)	(44.18)
Multiple	-	-	-	-	-	2	3	1	8	12	11
Lyeloma	-	-	-	-	-	(2)	(3.56)	(1.44)	(11.45)	(19.58)	(24.30)
Leukaemia	4	6	3	-	2	3	7	9	9	21	17
	(2.86)	(4.64)	(2.20)	-	(1.68)	(3)	(8.30)	(13.0)	(12.88)	(34.26)	(37.55)

[d] Rate per 100,000 of population at ages given, rounded to two decimal points, is shown in parentheses.

4.1.3 Willingness to Pay for Risk Reduction

Miller and Guria's individual statistical life valuation is used in this model. This study found average individual WTP to avoid a fatality was $2.84 million. WTP to avoid a non-fatal injury (which was serious enough to involve interruption to the work routine) of $14 200, derived from the Moore and Viscusi and Miller and Guria studies, is also used in this model.

4.1.4 Agrichemical Exposure Duration

In order to develop a model that examines the chronic risks of agrichemical exposure, it is necessary to calculate the effects of exposure duration on farmers' cancer mortality risks. The duration of agrichemical exposure is generally considered one of the most important factors in assessing chronic agrichemical hazards to human health (WHO).

Barthel (1981), in a study of lung cancer risk in German agrichemical-exposed male farmers, found that there was a statistically significant relationship between the total years of exposure and lung cancer SMR. Standardised mortality rates of 1.2, 1.7 and 3.0 were found in subjects with less than 10 years exposure, 10-19 years exposure, and greater than 19 years exposure, respectively.

Blair *et al.* (1983), in a study of agrichemical applicators in Florida, also found that the ratios of directly adjusted standardised mortality rates from lung cancer rose with the number of years licensed to spray, with SMR's of 1.0, 1.75 and 1.86 for those licensed for less than 10 years, for 10-19 years and for 20 years or more, respectively.

These studies provide evidence that cancer mortality risk is significantly increased in subjects that have a longer agrichemical exposure history. Farmers' cancer mortality risks were adjusted by a factor to account for the effects of exposure duration. Table 5 presents the adjustment factors used in the model.[11]

Table 5: The Effects of Agrichemical Exposure Duration on Cancer Mortality

Length of Exposure (Years)	Adjustment Factor
>10	0.67
10-19	1.08
20+	1.44

4.1.5 The Cost of Risk Reduction

The New Zealand Agrichemical Users' Code of Practice provides specifications for minimum protective clothing and respirator requirements for agrichemical use, by agrichemical toxicity class (NZAET). Research by Scully, Brush and Sheppard into agrichemical usage indicates that the majority of farmers commonly use class 3 'poisons', or agrichemicals of a lower toxicity. The annualized cost of the minimum protective equipment requirements for the mixing and application of 'poisons' is $220 (Protector Safety Limited 1994a). The replacement rate for agrichemical protective equipment is estimated as one year for the average farmer (Protector Safety Limited 1994b). As agrichemical protective equipment for the average farmer is estimated to require yearly replacement, a one-period choice model is used.

4.2 Empirical Specification

Brush and Clemes (1994) have stated that the health related monetarised benefits of agrichemical protection over a farmers agrichemical use history and lifespan can be represented in a model by the sum of the savable costs of acute (Equation 1) and chronic (Equation 2) health risks caused by non-protected agrichemical exposure. The sum is derived by calculating an average farmer's agrichemical exposure risk in the i^{th} year. Brush and Clemes (1994) original model however used a measure of average total cancer mortality risk derived from the aggregated findings of epidemiological studies that investigated cancer mortality risk for a limited number of cancers. This specification had the effect of significantly overestimating the actual exposure related health risks and consequently the stated monetary savable costs from non-protected agrichemical use. The refined model presented below incorporates the significant findings of Blair *et al.* (1992). They concluded that farmers' cancer mortality risks were only significantly increased for four specific cancers that could be etiologically linked to agrichemical exposure.

[11] The adjustment factors in Table 5 were derived from the findings of Barthel and Blair *et al.* (1983). The SMR's for each study's exposed group, categorised by their exposure history, were divided by the SMR finding for the total sample. The adjustment factors used in this model were derived from the aggregated findings of the two studies. A mean of one is not implied as there was not an equal number of subjects in each group.

(1) $A_i = R^a SV_{nfa}$

Where:

A_i = Cost of acute health problems, per farmer, in year i, caused by agrichemical exposure.

R^a = Risk of acute health problems, measured as a probability, caused by agrichemical exposure resulting in an interruption to the work routine.

SV_{nfa} = Statistical valuation of a non-fatal agrichemical accident requiring interruption of the work routine.

(2) $C_i = LE_k R^{CH} SV_F$

Where:

C_i = Cost of chronic long term exposure to agrichemicals in year i.

LE_K = Adjustment factor for cancer mortality risk (SMR) by the length of agrichemical exposure (K).

R^{CH} = The age group related elevated cancer mortality risk from chronic occupational agrichemical exposure in year i ($_{4,j=1}CR_j(MRR_j-1)$. This is the sum of the products of the elevated MRR for the jth (j=1,2,3,4) agrichemical exposure related cancer type and the male age group related risk of mortality for that specified cancer type.

SV_F = The statistical valuation of a fatality (statistical life valuation).

CR_j = The age group related cancer mortality risk for the specified cancer type j for New Zealand males.

SMR = Standardised mortality rate: the increased risk of mortality due to occupational agrichemical exposure.

MMR_j = Meta-relative risk: the standardised risk of mortality for farmers from the specified agrichemical related cancer type j due to occupational agrichemical exposure.

7. Model Results

Table 6 presents the direct lifetime costs and benefits of agrichemical protective equipment use for the average farmer. Benefits are the saved costs of increased life expectancy. Six typical cases are shown for the average farmer at various ages and with different agrichemical exposure histories.[12]

The replacement rate for agrichemical protective equipment, for the average farmer, is yearly, and thus costs and benefits are calculated for each yearly replacement decision period. The costs and benefits for acute agrichemical risks are calculated over the average farmers working life,[13] and the costs of chronic exposure over the average expected lifetime of the farmer.[14]

[12] The findings in Table 6 represent an average farmer's working life, however the replacement decision for protective equipment is made by the farmer on an annual basis. Calculations for each single replacement period, used to present the aggregated findings in Table 6, however also indicated that in no single period were the replacement costs of protective equipment greater than the WTP for prevention of acute and chronic agrichemical poisoning risk in that same period.

[13] The model assumes that farmers will retire from active agricultural employment at age 65.

[14] The average expected lifetime of a New Zealand male is 72 years (Statistics New Zealand).

Table 6: Average Direct Lifetime Costs and Benefits of Agrichemical Protection

Farmer Age	Exposure History (Years Exposed)	Cost of Protective Equipment	Saved Cost of Acute Poisoning Risk	Saved Cost of Chronic Poisoning Risk	Total Saved Costs of Acute and Chronic Health Risk	Benefit-Cost Surplus
20	0	9,900	12,780	990	13,770	3,870
25	5	8,800	11,360	985	12,345	3,545
30	10	7,700	9,940	975	10,915	3,215
35	0	6,600	8,520	914	9,434	2,834
40	20	5,500	7,100	953	8,053	2,553
45	0	4,400	5,680	793	6.473	2,073

In the case of an average 20 year old farmer, who has had no previous history of agrichemical use, Table 6 indicates that the costs of agrichemical protective equipment over this farmers working life with agrichemicals is $9,900. It is less for men with less life exposure in front of them. Valuing the risks of acute and chronic agrichemical poisoning for the same average 20 year old farmer, using the findings from the surveys on farmers' acute poisoning incidence, and the chronic agrichemical exposure related cancer mortality risk estimates derived from Blair *et al.* (1992), indicate that the saved cost (lifetime benefit) of the non-use of protective equipment is $13,770 over the average farmers lifetime a sum well in excess of the lifetime cost of protection. The findings for the other average farmer cases in Table 6 identify significant saved costs (benefits) in excess of the cost of protection also.

8. Limitations of the Model

The risk estimates that have been sourced may under/or overestimate the actual risk from agrichemical exposure. A number of other factors may also be responsible for understating the costs associated with risk reduction strategies and the WTP for preventative action.

8.1 Overestimation Factors

Through normal farming practices, farmers are exposed to many other potential carcinogenic substances. The potential etiologic factors for non-Hodgkin's lymphoma and multiple myeloma, which may be associated with agricultural occupations, fall into three major categories: agrichemicals, zoonotic oncornaviruses and chronic antigenic stimuli. However, the nature of the survey instrument used to derive the findings that are presented in the studies reviewed in this report, prevents a determination of the extent to which these etiologic factors contribute to the excess of non-Hodgkins lymphoma and multiple myeloma.

A possible excess risk associated with exposure to zoonotic viruses has been suggested by the high rates of cancer of the lymphatic and haematopoietic system among veterinarians (Blair and Hayes 1982). However, although there is no proven evidence of virus induced tumours in humans there are clear cut cases of virus-induced malignant lymphomas in animals (Malignant Lymphoma 1978). Other possible etiologic risk factors are suggested by the hypothesis that non-Hodgkins lymphoma and multiple myeloma may occur after prolonged antigenic stimuli to lymphoproliferation (Greene; Blattner). However, it has not been determined if these diseases are more prevalent in agricultural communities (Pearce, Smith and Fisher 1985). Further investigation of these etiologic factors would be desirable.

8.2 Underestimation Factors

One important factor that may underestimate the chronic exposure risk calculations used in this study is the latency period of cancer. The farmer-cancer mortality association is generally evaluated by considering the occupational class that is recorded on the death certificate, or is coded from data collected at the time of cancer diagnosis, or even later if cancer registration is delayed. If the agrichemical exposure related cancer latency period is similar to that for other cancers initiated by chemical exposures, etiological exposures would have occurred many years earlier, probably in the period 10 to 30 years prior to diagnosis. The occupation at the time of diagnosis is only relevant if the patient has had the same occupation for many years. This will not always be the case, although the number of changes which would involve movement from one major occupational classification to another is probably very small (Smith *et al.* 1982).

The acute and chronic risks of agrichemical poisoning to farmers, in the absence of protective equipment use, that are reported in this study, may also be understated due to the existing research methodology which generally takes no account of protective equipment use, or does not interpret the findings in relation to agrichemical toxicity. As an example of this underestimation, Cantor *et al.* (1992) reported a significantly higher relative risk for farmers who had handled agrichemicals without protective equipment than the total sample that had handled agrichemicals with or without protective equipment.

White has further considered reasons why the risk of farmers getting cancer in many studies appear to be statistically small. Farmers are one of the largest occupational groups with exposure to agrichemicals, but they are also less likely to suffer from ill health generally. This is usually attributed to their higher level of fitness, younger average age, and higher intake of fruit and vegetables. Farmers are also less likely to smoke than the average person (Donna *et al.* 1984). Blair *et al.* (1992) in their review of the literature found that in all of the 21 studies analyzed, the 'healthy worker' effect contributed to an absence of a greater risk to farmers from most major diseases, including all causes, all cancers, and ischaemic heart disease. The excesses among farmers for a few specific cancers, against a background of low risk for most other diseases, however suggest work-related exposures are a factor in increased cancer mortality risks.

Further, there is considerable evidence that the risks to human health from chronic exposure to agrichemicals include inhibition of the nervous system (Ngatia and Mgeni), and behavioural impairment in terms of neurological and psychological effects (Hayes; Savage *et al.*). These concerns could be taken into account in future work.

8.3 Underestimation Of The Actual Costs Of Risk Reduction

It is possible that the model developed for this study, which estimates the costs of recommended protective equipment, but does not estimate the costs of complementary education and training, may underestimate the actual costs of agrichemical risk reduction strategies. In addition, the indirect costs to farmers of wearing protective equipment, including time costs and discomfort costs were not estimated.

8.4 Underestimation Of The Actual WTP For Risk Reduction

A refinement of the WTP approach involves recognition of the fact that safety improvements also have 'direct' economic effects, such as avoidance of net output losses,[15] material damage and medical costs. To the extent that people, in the main, appear not to take account of such factors in assessing their WTP for improved safety, and there is some evidence that they do not (Jones-Lee, Hammerton and Phillips), then an allowance for these factors should be added to values of 'statistical life' and safety.

Finally, the analysis of the costs and benefits of implementing recommended agrichemical practices has not examined the considerable legislative responsibility imposed on agrichemical users and the potential costs to farmers of non-compliance. In New Zealand the Noxious Substances Regulations 1954 and the Health and Safety in Employment Act 1992 provide for the imposing of considerable penalties for non-compliance, up to a maximum of $100 000 and/or imprisonment up to a year in the case of the Health and Safety in Employment Act 1992. S10(2)(b) of the Health and Safety in Employment Act 1992 considers the responsibility of employers to provide suitable clothing and equipment. S17 extends this requirement to self employed people. In Australia each state has legislation controlling the use of agrichemicals. For example, in Queensland S9(2)(f) and S10(1)(2) of the Workplace Health and Safety Act 1989 mandate the provision of personal protective equipment to employees, employers and self employed persons. Penalties for offences under the Act range from up to $30,000 and 6 months jail for individuals, and up to $180,000 for organisations. In New South Wales similar provisions operate under the Occupational Health and Safety Act 1983. Penalties for offences under this Act range from up to $25,000 and 2 years jail for individuals, and up to $250,000 for organisations.

9. Conclusions

The findings of this study indicate that even with the limitations of the model there is a significant benefit-cost surplus in the use of agrichemical protective equipment.

There is however strong evidence of a considerable percentage of farmers not complying with the recommended agrichemical protective equipment requirements (Pryde; Houghton and Wilson; Scully, Brush and Sheppard; McMullen *et al.*; Kondinin Group). This significant market failure may be attributed to informational failures by farmers that result in problems of risk perception and response. These informational failures may be attributed to a number of factors. Firstly, although the safe management and use of agrichemicals is an important issue for most producers in the primary sector (Gray), only 14.2 per cent of New Zealand farmers have ever attended a training course on agrichemical application (Scully, Brush and Sheppard). Further, as at January 1994, only 7.8 per cent of Australian livestock farmers had been formally trained in the use of farm chemicals (McGuffog and Company). Despite this lack of formal agrichemical training there is evidence that the majority of farmers generally rate their knowledge of

[15] The discounted present value of the excess of an individual's expected future output over and above his future consumption is defined as his 'net output' and would clearly represent a direct loss to the rest of society should he die prematurely.

agrichemical practices, in spite of clear evidence to the contrary, as being good to excellent (Scully, Brush and Sheppard; McGuffog and Company). This perception of adequate agrichemical knowledge, and inadequate short term feedback due to the significant lag in the onset of long term chronic effects of agrichemical exposure (Sharp *et al.*) adds further to problems in risk perception. Secondly, farmers may also underestimate risk by believing that accidents are a rare event, only happen to other people, or can be prevented by appropriate evasive action. These beliefs reduce the incentive to wear protective equipment. The conclusions drawn from these studies indicate that these combined factors have contributed to a significant percentage of farmers underestimating the health risks from agrichemical exposure, and consequently undervaluing the implementation of 'safe' practices, especially the use of protective equipment.

The evidence of a significant market failure with respect to information on safe agrichemical use leads to a consideration of various risk reduction strategies that may redress the informational failure. Although there may be a potential argument for government intervention in this area, there is currently sufficient legislation in place in New Zealand in the form of the Noxious Substances Regulations 1954 and the Health and Safety in Employment Act 1992 and in Australia under the various state legislation, that governs agrichemical and occupational safety and provides for considerable penalties for non-compliance. However, despite the evidence of non-compliance, a thorough review of the New Zealand agrichemical and occupational safety case law has found no evidence of any non-compliance cases being brought forward under the relevant provisions (Brush 1995).

In view of the apparent lack of enforcement of the New Zealand agrichemical and occupational safety legislation, the significant informational failure, and the overestimation by Australian and New Zealand farmers of their agrichemical knowledge, that may act as a considerable barrier to farmer's voluntary participation in agrichemical education programmes, it may be necessary for agrichemical application training to be made compulsory for farmers. Comprehensive procedures for monitoring agrichemical practices and enforcement of the legislation may also be warranted.

Finally, in support of the benefits of agrichemical training participation, Sutherland found that 77 per cent of respondents who had undertaken farmer chemical user training in New South Wales had modified their farm chemical practices as a result of training participation. Fifty three per cent of respondents who had modified their practices also indicated they had greatly improved safety measures.

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