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# THE VALUE OF "ALMOST" PERFECT WEATHER INFORMATION TO THE AUSTRALIAN TERTIARY SECTOR

*by*
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*Abstract:*

*This paper is an attempt to determine the extent to which Australian tertiary sector organisations stand to gain from improved weather forecasts. An upper limit to this amount must be the sum of the maximum savings afforded by weather forecasts sufficiently accurate ("almost" perfect) to result in weather-error-free decisions for each organisation. The paper presents the results of a survey of tertiary sector organisations undertaken to determine the amount of these potential savings. The paper discusses operational improvements to increase the usefulneww of forecasts, and also discusses the structure of the weather forecasting industry in general.*

*Keywords:*

*DECISION ANALYSIS; ECONOMIC VALUE; INDUSTRIAL ORGANISATION; LIABILITY; METEOROLOGY; PERFECT INFORMATION; SURVEY; WEATHER FORECASTING; WELFARE ECONOMICS*

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No-one can be certain of future weather, and the uncertainty associated with weather increases as we try to look further into the future. Governments (and taxpayers) spend increasingly large amounts of money trying to forecast the weather, with increasing accuracy. But as the science of forecasting has progressed the technology associated with forecasting has become more expensive; radar, satellites, electronic data processing have all improved the scientific accuracy of weather forecasts, but at a cost. (Total expenditure on the Australian Bureau of Meteorology has risen from $1.1 million in 1957/8 to $6.5 million in 1967/8 to $37.5 million in 1977/8.)

For various reasons weather forecasting is predominantly a government-run service, with the few charges for weather information being much less than the cost of operation, which has been borne by the taxpayers, via government payments to the weather service. There are arguments that this is correct, as we shall see below, in Section 6, but for the moment we note that, in the present atmosphere of austerity, there are pressures for all government activities to be examined for cost-effectiveness. It is the purpose of this paper (1) to make some general comments about the value of information, (2) to survey the value of weather forecasting to the tertiary sector of the Australian economy, (3) to discuss how the value of forecasts could be improved through operational, as opposed to scientific, advances, and (4) to ask some general questions about the meteorological industry.

## *1. THE VALUE OF "ALMOST" PERFECT INFORMATION*

By "almost" perfect information we mean information sufficiently accurate to enable error-free decisions to be made. That is, if the decision is whether or not to carry extra fuel on a flight tomorrow, it is sufficient for an error-free decision to know that weather conditions will be such as not to delay landing; it is not necessary to know perfectly the wind direction or the temperature and relative humidity. It is obvious that the degree of perfection sufficient will vary with activity and decision maker: it is not possible to formulate a more objective definition. We leave it to the individual organisation or decision maker to decide just how much perfection is sufficient. (This concept of sufficiency of a forecast for the purpose of a specified weather-information user was introduced by Nelson and Winter (1964), and is exemplified by Lave's (1963) study of the value of better weather information to the raisin industry and by Howe and Cochrane's (1976) study of better weather information and urban snow storms.)

We can put an upper limit on the value of improvements to the weather services by asking what the value to society (or a sector of society) of "almost" perfectly accurate weather information would be. A rational decision maker would not pay more for imperfect than for "almost" perfect information: the value of "almost" perfect weather information therefore becomes an upper limit on the amount he would be prepared to pay for improvements to the weather service, to result in weather information of improved quality. We shall argue that the potential gross benefit from improvements in the quality of weather information accruing to the Australian tertiary sector is large; no examination of the <u>cost</u> of such improvements is made.

The commodity (the weather forecast) produced by the weather service is information: imperfect information about future weather conditions. The information provided by the weather service can be both an intermediate good (when used by firms and organisations in the course of their operations) and a consumption good (when used by individuals for their own benefit). If we are considering improved weather information as a consumption good it is hard to know how to evaluate it [Richardson (1980)], but if we are considering improved weather information as an intermediate good we can evaluate it in terms of the increase in net revenue that results from its use. In Section 3 we describe a survey of tertiary sector enterprises in an attempt to evaluate the potential benefits possible from improved weather forecasts as intermediate goods.

It is sometimes difficult to place a value on such information. It may only be *ex post* that its value (or worthlessness) becomes clear. *Ex ante*, weather information is only of value to an organisation if the organisation can conceive of information on which it could act to increase its expected net revenue. That is, if there is no possible weather information which the organisation could use to its benefit then, as a rational decision maker, it would place a zero value on weather information, that is, it would not be willing to pay to reduce its uncertainty about future weather.

We must distinguish here between the value (or cost) of weather, and the value (or cost) of weather information. Even if weather information were perfect (or almost so), and the forecast accurately stated what future weather would be (or at least sufficiently accurately for error-free decisions to be made), nevertheless if the cost of protection against adverse weather were greater than the loss to be suffered if adverse weather occurred and protective action had not been taken, then the net revenue of the organisation could not be increased as a result of the (accurate) forecast, and the forecast would be valueless, even though ("almost") perfect. Another way of putting this is to speak of "weather sensitive" organisations and "weather-information sensitive" organisations. The first are all those which can suffer losses because of adverse weather; the second are those which can reduce these losses by taking protective action (usually at a cost).

As an example, consider the case of a cinema owner: if the weather on a Saturday afternoon is cold and wet, he can expect that more people will want to see a movie than will want to spend the time out-of-doors; similarly, if the weather is hot and sultry, he can expect people to seek relief in an air-conditioned cinema. Thus his net revenue will probably increase on cold and wet or hot and humid days, and fall on fine, sunny days. But will he be prepared to put a value on a forecast (to reduce his uncertainty about future weather) before he knows what the forecast is? That is, what is the *ex ante* value, if any, of weather forecasts to him? If there is nothing he can do to take advantage of (or conversely to protect himself against) the weather, then the decreased uncertainty from a weather forecast is valueless to him: if the matinee performance will occur whatever the weather, and if the air-conditioning (suitably adjusted) will operate anyway, then it is hard to see what difference the weather *forecast* could make to him. His take at the box-office might well be affected by the weather, but foreknowledge of the weather, even if perfect (or almost so), could not, in his day-to-day operations, result in greater net revenue for the cinema. The cinema is a weather sensitive, but not a weather-information sensitive, organisation.

If, however, the cinema were situated in North Queensland, then forecast of a cyclone might be of value to him: with a warning in time, he could take protective action to reduce the losses from the cyclone in terms of damage and disruption to his business before the cyclone struck (by dismantling the screen, packing up the projectors, etc.), and forecasts would have a definite value to him, even before he knew them: the cinema would then be a weather-information sensitive organisation.

It is possible of course that the actual forecast, when received, has no value, or at least no direct value: if the North Queensland forecast does not predict a cyclone, then the only value to the cinema owner is just that: no cyclone is likely. By our criterion of a forecast's only having value if it can be used to improve the expected net revenue of an organisation, the information has zero value. (This assumes that in the absence of the forecast the cinema owner would have incurred no costs associated with protective action.)

We distinguish here between weather forecasts and climatic data (measurements of past weather patterns), which are always assumed to be known, and hence constitute a minimum level of information on future weather (by extrapolation). We do not regard actions depending on knowledge of climatic data alone (such as capital investments, with particular construction standards and site locations) as "protective actions;" we regard the former as reflected in fixed costs and the latter in variable costs of production. The more variable (uncertain) the weather (as reflected in the climatic data) and the more severe the climate, the higher the fixed costs in general, for a single organisation; the industry-wide effects depend on the structure of the industry.

Since Thompson and Brier (1955), the literature has used the two concepts of "cost of protection" (the cost C involved in taking protective action against the occurrence of adverse weather), and "weather-related loss" (the loss L suffered when adverse weather occurs and no protection has been undertaken). If a series of decisions has been made of whether or not to take protective action against the possibility of adverse weather, the results may be represented as shown below, where a, b, c, and d are the observed frequencies, adding to N.

Generalised contingency table relating decisions for protective action and frequencies of occurrence (W) or not (No W) of adverse weather.

| | | Decision | |
|---|---|---|---|
| | | Do not protect | Protect |
| Observed weather | No W | a | b |
| | W | c | d |

The total weather-related losses E are given by the sum of the cost of justified protection dC, plus the cost of unnecessary protection bC, plus the unprotected losses due to unforeseen adverse weather cL; that is,

$$E = (b + d)C + cL. \tag{1}$$

Had sufficiently accurate weather information been available, the only expense would have been the cost of protection against adverse weather, previously unforeseen and previously foreseen, E′:

$$E' = (c + d)C. \tag{2}$$

Subtracting equation (2) from equation (1), we see that the potential total gain from improved weather information (E − E′) is given by

$$E - E' = bC + c(L - C), \qquad C < L, \tag{3}$$

that is, the cost of unnecessary protection bC plus the net reduction in costs of protecting against previously unforeseen adverse weather c(L − C).

It is the potential total gain (E − E′) that we sought in the survey described in section 3 by asking organisations firstly what their total weather-related losses E had been (irrespective of whether or not protective measures could have been taken against the adverse weather), and secondly what their avoidable losses (E − E′) had been (losses which could have been protected against had adequate information been available in time). The extent to which the second of these, the avoidable losses, is non-zero is an indication of the weather-information sensitivity of the organisation. (Note that to be adequate, information must be believed: a succession of incorrect forecasts may lead to a reduction in the credibility of later forecasts - the "boy who cried: Wolf!" syndrome.)

Thus the survey left it up to the individual organisation to decide the value of avoidable losses - only the individual organisation was in a position to know whether the protection costs had been low enough and the adverse weather losses high enough for protection to have been worthwhile, that is, L > C. It was also left to the individual organisation to decide just what degree of perfection in weather information was sufficient for error-free decision-making, to decide what "almost" meant. Of course, such a question might have been a novelty for the organisation, and it is possible that the very act of gathering data about the value of weather forecasting might have altered its future value to the organisation.

Decision-analysis theory enables us to draw conclusions about the value of weather information to a single organisation. Assuming the structure of each tertiary industry, we could draw similar conclusions about the value to the industry of weather information, but the fact that the tertiary sector is part of a mixed economy forbids such theoretical generalisations. Thus we discuss the empirical value of weather information independently of industry structure. In section 4 we speculate how these empirical results conform with the predictions of a theoretical model.

## 2. *WEATHER FORECASTS AND TERTIARY INDUSTRIES*

The tertiary, or service, sector is generally taken to include all activities not included in the primary (agriculture, forestry, fishing, and hunting; mining) and the secondary (manufacturing) sectors. The tertiary sector thus includes electricity, gas, and water; construction; transport and storage; communication; wholesale and retail trade; finance, insurance, real estate, and business services; public administration and defence; community services (health, education, welfare, research, and public safety); and entertainment, recreation, restaurants, hotels, and personal services. This section briefly considers how such industries might be weather sensitive and weather-information sensitive, using comments of the questionnaire respondents.

Every stage of construction is to some extent weather sensitive. With warning in sufficient time a contractor can reduce his weather-related losses. Russo (1966) estimated that between 3.5% and 11.5% of total U.S. construction industry expenditure had been lost through adverse weather conditions in 1964. He further estimated that between 10% and 17% of this loss could have been saved with the use of appropriate weather information, with no change in forecasting accuracy. Construction contractors in Australia may place a very low value on short-run (1-5 hours) weather forecasts of rain: under the labour contracts in use the contractor cannot lay off his workers with only a few hours' notice, and so there is very little opportunity for him to protect himself against these weather-related costs. Another way of putting this is to say that the costs of protection, the costs of breaking the labour contract and laying off his workers (law suits, blackbans, etc.), are much higher than the losses (the wages paid for no work) the contractor suffers if it rains. Thus, even if certain of rain, he can take little action in the short run: although weather sensitive, he is almost weather-information insensitive in the short run.

We discuss in section 5 the air transport industry, which because of institutional arrangements about fuel reserves may suffer greater losses from inaccurate forecasts than from the adverse weather conditions themselves. The weather elements that most frequently influence airline operations are those involving visibility and runway conditions. With warning, the airline can take some measure of protective action and is thus weather-information sensitive. A study of commercial air carriers in the U.S. [United Research Incorporated (1961)] concluded that losses were of three forms: firstly, cash losses when airlines were forced to cancel, delay, or divert their flights; secondly, short- and long-term costs resulting from landing accidents; and thirdly, losses from the reduction in demand for air travel as a result of its unreliability in periods of bad weather.

The main weather elements affecting water transport are fog and winds, especially cyclones. For ocean voyages a million-dollar international weather routing industry has arisen, providing the ship's Master with the route that will lead to the fastest passage with the maximum safety for his crew and the greatest security for his cargo and hull in the face of the weather forecast along the proposed course [Mayer (1979)].

Adverse weather often leads to increased demand for communication services, so that they must be prepared to meet the highest traffic and the lowest operating conditions at the same time. But electronic communications networks are only marginally weather-information sensitive. The printed communications media, particularly newspapers, can be affected by weather: inclement weather will lead to sizeable falls in street sales, and unless accurately forewarned, newspapers might incur costs from unsold copies.

The retail trade is particularly affected by weather, and the move to "one-stop shopping", with different stores and shops accessible from a covered mall, can be seen as an attempt to reduce weather factors in sales. Department stores may be able to schedule more sales personnel and to display and advertise particular lines on days when "buying" weather is forecast. Longer-term forecasts could aid stock-building and advertising planning. Our survey confirmed the evidence of wide-spread awareness of the weather-sales relationship, which has been analysed in several studies discussed by Maunder (1970).

Seasonal weather changes obviously have a large effect on business sales and construction, and consequently on demands for credit from commercial banks. The extreme winters in the north-eastern U.S. in recent years, and last winter's weather in northern Europe, almost brought commerce to a halt, and have led to a greater awareness of the importance of weather forecasting [Anon (1977), Snyder (1977), Smith (1977), Anon (1978)].

The prices on commodities markets can vary with the weather: with the actual, the reported, and the expected weather. Snyder (1977) reports that when the daily low in Orlando, Florida, fell below zero degrees Celsius for several successive days in January 1977 the price of frozen orange-juice futures (May 1977 contracts) rose from 10 cents/lb to 70 cents/lb in two weeks (the maximum speed of rise) as much of the orange crop was immediately destroyed. Australia has no operating commodities futures markets, but did they exist study of such fluctuations might reveal much about how weather information and forecasts are valued, and how their value changes through time.

To the insurance underwriters the meteorologist can be of great help in establishing the degree of weather-related risk (and hence the premia) and in helping to settle claims. However, the properly diversified insurance company is not directly generally affected by the weather, and thus can make no use of short-term forecasts.

Tourism is greatly affected by weather conditions. With a weather-sensitive demand for tourist facilities, resort operators might avoid losses through use of weather forecasts. Snow resorts, for instance, could vary their staffing in response to forecasts of snow, rain, temperatures, and winds.

## *3. A SURVEY OF THE TERTIARY SECTOR IN AUSTRALIA*

In Australia some divisions in the tertiary sector are dominated by government enterprises. In particular, electricity/gas/water, communications, and community services are almost completely wholly government enterprise divisions. Although the existence of large government monopolies in some divisions made surveying easier, it made processing the survey more difficult because of inconsistencies in published aggregate data.

Questionnaires closely based on those of a similar survey in the U.S. by Thompson et al. (1972) were sent to 131 private firms and public corporations around Australia in the tertiary sector. Special attention was paid to the commercial aviation and construction industries, since Thompson's results indicated that these would be especially sensitive to improved weather information. The questionnaire is presented in Appendix A. The questionnaires were dispatched following telephone contacts, which may explain the relatively high response rate of 46%.

In selection, we aimed to survey as many tertiary sector organisations as possible, but lack of adequate industry lists was a problem in obtaining names and addresses. In the cases of electricity, gas, water, sewerage, railways, ports, and public works (including road construction), questionnaires were sent to all government agencies responsible in Australia. For air transport, questionnaires were sent to Qantas and to all domestic charter companies and scheduled airlines. All three government communications agencies (Overseas Telecommunications Commission, Australia Post, Telecom Australia) were approached. The major freight forwarders and private shipping firms were approached. In construction, an industry with many large and small firms, we approached those twenty six most prominent whose names could be determined from industry lists. Major publishers, all major oil companies, major department stores, major accommodation chains, and major insurance companies were also approached.

Following Thompson we asked each organisation to state, question 2, its total weather-related losses, E in equation (1), and, question 5, its avoidable losses, (E - E′) in equation (3). As well as asking for each of these to be expressed in dollars, we requested that the first be expressed as a percentage of "total annual (gross) revenue" and of "total taxable income." We then assumed that there was no bias between the sample mean and the industry mean (that is, we assumed that the replies constituted a random sample), although, if anything, replies were likely to be biased towards larger, more weather-information sensitive organisations. We were able to calculate the weather-related losses for each industry from total business revenues for 1975/76 (the latest available) from Taxation Statistics 1976-77, [ATO(1978)], the Year Book Australia 1977-1978, [ABS(1978)], and Commonwealth Department of Transport data. The results of these calculations are shown in Table 2, with Thompson's percentages in brackets.

For the tertiary sector as a whole, the total losses for 1975/76 calculated from the survey ($1034 million), and the protectable weather losses ($220 million), must be approximate figures only, given the sampling difficulties involved and the problems of aggregate gross revenue statistics in a mixed economy. Moreover, question 2 on the survey, with the qualification "increased expenditures and/or decreased revenues," might have sought too much. Our aim was to gather data on weather-related expenditures and weather-related opportunity costs (revenues foregone), but it is likely that respondents would only have had data on the first, which would tend to understate total weather-related losses. This would, however, have no effect on the estimation of protectable losses.

The weather-related costs as percentages of total annual gross revenue in our survey can be compared with Thompson's percentages. The ratio of protectable losses to total losses (21%) compares with a ratio of 39% in the tertiary sector of Thompson's survey. Does this imply that the Australian Bureau of Meteorology is producing more accurate weather information than is the U.S. National Weather Service (leading to a smaller fraction of total weather losses still to be protected against here)? Could it mean that there is more uncertainty (less predictability) in the nature of U.S. weather patterns? Could it follow from their being more extreme than the (relatively) benign Australian weather patterns?

It is seen that the Electricity/Gas/Water industry in Australia incurs higher total and protectable losses than in the U.S. This might be due to the impact of droughts on both water supply and hydro-electricity generation. In the construction industry the protectable costs are only 8% of total weather-related costs, compared with a proportion of 33% in the U.S. This difference may partly be sampling error: it is possible that there is a bias towards residential and general building in the survey, away from highway, heavy, and specialised construction, which being more weather sensitive is possibly more weather-information sensitive. The difference may also be explained, as suggested above, by labour contracts reducing the extent to which wage costs can be reduced quickly during adverse weather by laying workers off.

Table 2 shows that although, as a percentage of gross revenues, Other Transport (road, rail, water transport and storage) incurs high total weather-related costs, "almost" perfect weather information would result in proportionately much greater savings for the Air Transport industry. In a lengthy reply to the questionnaire, Paul Phelan (1979) of Bush Pilots Airways Limited gave several possible reasons for this. He stated that losses were incurred through (1) inadequate and inaccurate forecasting, and (2) legal reserve fuel requirements directly related to the official weather forecast.

Phelan pointed out that direct weather-related costs were small, compared to costs incurred because of inaccurate forecasts. The Government, through the Department of Transport, has apparently decided that the losses suffered in the case of adverse weather with no protection (that is, in the case of insufficient fuel to divert to an alternative destination or to hold at the original destination until a safe landing is possible, leading to a forced landing with possible injuries and deaths) are so high compared to the costs of protective action (that is, holding sufficient fuel reserves to hold or divert safely, with the consequent reduction in payload available and thus in profitability) that protective action must be taken even if the probability of adverse weather is only small. We can express this mathematically, as shown in Section 5.

Thus the Department of Transport leaves no room for interpretation of the official forecast by the airline, and no possibility of its use of unofficial forecasts, despite the occurrence of unforeseen conditions at times. Several respondents to the survey apparently believed that forecasters from time to time predict worse weather conditions than justified, which if true may be in response to the possibility of unforeseen conditions and to the tendency to err on the side of safety. Phelan praised the quality of the basic weather data gathered, but felt that changes in the presentation of the weather information would be of use. This is a point taken up with respect to the probability of occurrence of the predicted weather conditions in Section 5 below.

As far as is known, no other estimates of weather-caused costs for the Australian tertiary sector have been published. We emphasise again that the value of $220 million is the estimated amount that could have been saved in the tertiary sector in 1975/76 if forecasts had been "almost" perfect and known to be so: it is not a measure of the total value of weather forecasting to the sector. (The latter value comprises the total losses incurred in the complete absence of official Bureau of Meteorology forecasts.) In Section 5 we discuss how the expected expenses of decision-making with imperfect weather prediction may be reduced (how the protectable losses may be reduced) through changes in presentation of the weather information, without improvements in the scientific accuracy of the forecasts.

Another analysis of the survey data was concerned with respondents' replies to the question concerning the minimum period of advanced warning necessary in order to take protective measures against predicted adverse weather. A summary of the data by industry is presented in Table 3, which gives the percentage of respondents who designated the indicated forecast period as the minimum required for an adequate warning against predicted adverse weather.

An inspection of Table 3 reveals considerable variation in the minimum period of warning. For the commercial aviation and communications industries the modal period is in the 1-5 hours range, while for the other industries the modal period is 12-36 hours or longer. These data agree on the whole with Thompson's U.S. data [Thompson et al. (1972)]. In general, the preferences revealed by the data seem reasonable: aircraft routes and reserve fuel provisions can be changed up to a few minutes before departure, and as a result airlines are interested in the latest forecasts. The construction industry, through its labour contracts, is constrained from taking much protective action in less than 24 hours, and the figures reflect that it is interested in warnings up to a minimum of five days in advance.

The survey data on the relative importance (rank by frequency of mention) of the particular elements are presented in Table 4. Rain was the most important element for all industries but Air Transport, which listed rain equal fourth with wind and temperature. As expected, visibility was very important to the transport industries. Hail, drought, snow, and thunderstorms were all mentioned for at least one industry.

Except for the comments from the air transport companies mentioned above, no comments were more than fragmentary. Note that where surveyed the three tertiary divisions of Finance, Insurance, Real Estate and Business Services; Public Administration and Defence; and Community Services indicated that they suffered negligible weather-related losses, and that improved weather forecasting would be of no value to them. Accordingly, they have been excluded from Tables 2, 3, and 4.

## 4. *ECONOMIC ASSUMPTIONS*

In this section we make the assumption that weather-information sensitive Australian tertiary industries are competitive. This enables us to draw conclusions about the effects of improved weather information on the outputs and income distribution in the teriary sector as a whole. Although the sector exhibits strong elements of oligopoly, we assume competition as a first approximation, since oligopolistic models do not yield conclusions on these issues as directly as do competitive models.

What we are attempting to do through the survey and the aggregation of protectable losses across organisations and industries in Table 2 is to estimate the maximum willingness to pay (or increase in producers' surplus) of the Australian tertiary sector associated with improvements in the quality of weather information to the point where all weather-related decisions are error-free. We might think of this improvement as corresponding to a fall in the (expected) price of an input factor of production demanded by tertiary sector organisations. With no other price changes this increase in producers' surplus would equal the welfare gain to the whole economy from the provision of "almost" perfect weather information to the tertiary sector.

But other prices are unlikely to remain constant. A fall in the price of a factor input will imply a downwards shift in the supply curve of the industry. (This reflects the fact that the lower the price of the factor input, the lower the marginal cost of producing any quantity of the output.) Conversely, a decrease in the price at which the output can be sold will imply a shift downwards in the demand curve for the factor input. So, with competitive output markets, we should expect an improvement in the quality of weather information to result in increased sales of outputs from tertiary sector industries, at lower prices.

With no income effects (and the low percentages in Table 2 indicate that these would be negligible for all tertiary industries), the lower prices of outputs will result in a rise in consumers' surplus and a fall in producers' surplus. If each output is sold on a competitive market, with price equal to marginal social cost, than the fall in producers' surplus is exactly offset by the rise in consumers' surplus, and the change in net welfare of the community is measured by the rise in producers' surplus on the factor input market (the maximum willingness to pay for the improvements), given the shift downwards in the demand curve as the price of output falls. The amount of $220 million is thus a measure of the increase in the net social welfare from the provision of "almost" perfect weather information to the tertiary sector.

To the extent that organisations surveyed made ceteris paribus estimates, without taking into account the induced downwards shifts in the demand curves for factor inputs, the amount is an overestimate, with double counting of the savings to the community from improved forecasts [Sugden and Williams (1979), page 143].

Some of the outputs produced in the tertiary sector may be sold at prices greater than marginal social costs. The "natural monopoly" industries of postal services, telecommunications, railways, and gas and electricity supply, with decreasing average costs, all fall into the tertiary sector; it is often the case that in these uncompetitive industries prices are set above marginal costs. In transport services with excess capacity the marginal cost is zero, yet prices are seldom zero.

It is possible that such organisations would not pass on their lower marginal costs to consumers through lower prices of output, but would wholly retain the savings themselves with unchanged sales of output. Although this would mean no increase in consumers' surplus, the increase in producers' surplus as measured would be equal to the net social welfare gain. If the lower marginal costs were passed on to consumers through lower prices of output, then the quantities of output demanded would increase, as would consumers' surplus. But since the price charged is greater than marginal cost, the fall in producers' surplus will be less than the rise in consumers' surplus, and there will be a net welfare gain from the price decrease.

To the extent that such price falls occur, the amount of $220 million is an underestimate of the increase in net social welfare. But since any market with prices above marginal costs is not competitive to begin with and since changes in such prices can be separated administratively from cost reductions, we do not consider the effect further. We conclude that the amount of $220 million is an overestimate of the increase in net social welfare of Australia which would have accrued from the provision of "almost" perfect weather information to the teriary sector in 1975/76. Thompson (1979) has agreed that the figure is an overestimate.

## 5. *OPERATIONAL ADVANCES IN THE VALUE OF WEATHER FORECASTS*

We start this discussion by examining the regulations of the Department of Transport on reserve fuel requirements for commercial airlines, as discussed above in Section 3. Following Thompson and Brier (1955), we can express the situation mathematically: when the decision under uncertainty is dichotomous (that is, to protect or not against adverse weather - to carry reserve fuel sufficient for diversion or not), and when the aim is to minimize the long-run total expense, the decision-making criterion is to take protective action if the expected loss otherwise is greater than the cost of protection. This can be formalised as

$$P \begin{cases} > C/L, & \text{Protect} \\ = C/L, & \text{Either} \\ < C/L, & \text{Do Not Protect} \end{cases} \quad (4)$$

where P is the probability of adverse weather (the probability that landing conditions will be sufficiently bad to justify diversion), where C is the cost of protection against adverse weather (the cost in terms of payload foregone of carrying sufficient reserve fuel), and where L is the loss with adverse weather and no protection (the expected cost of a forced landing, with the possibility of injuries, deaths, and damage both in and out of the aircraft).

This formulation assumes that decision makers are risk-neutral, expected total expense minimisers. The ratio of C/L will vary across activities and users, which opens the possibility of forecasts tailored to users in specific C/L ranges. If L is very much greater than C, then, to minimize long-run total expense, protective action should be taken even when the probability of occurrence of adverse weather (in the estimation of the forecaster, given all data) is small.

But in Australia at the moment forecasts are presented categorically: no information is included on the forecaster's estimate of the probability of occurrence of the forecast weather. Following Carter (1972), we assume that the categorically predicted weather event is that which is most likely to occur (that is, the modal value of the probability distribution), which, for a dichotomous situation, means the event which is predicted with a probability exceeding 0.5. If fog, say, is forecast, it must mean that the balance of likelihood is for fog occurring; that is the probability of fog is greater than 0.5. From equation (4), only if a particular user had a C/L ratio equal to 0.5 would he have no advantage to gain from probabilistic forecasts, since categorical forecasts imply probabilities of occurrence greater or less than 0.5.

In the case of air transport, both the private (airline) C/L ratio and the social (public) C/L ratio are likely to be very much less than 0.5, depending on the utility functions of the parties. Rather than the optimum long-run decision-making criterion of equation (4), it is likely in these circumstances that some form of "mini-max" strategy is used. (A mini-max strategy will attempt to minimise the likelihood of incurring maximum losses - for instance, a forced landing. Carter (1972) shows that mini-max decisions are designed to "over-forecast" adverse weather.)

Several authors have argued that there exists a potential for improving the economic value of weather forecasts, given the present state of the science of meteorology, by supplying decision makers with information about the degree of uncertainty in the forecast [Thompson (1962), Nelson and Winter (1964), Hutschke (1971), Carter (1972), Murphy (1976)]. Simply stated, if there are only two relevant weather states from the decision maker's point of view (for example, rain or no rain), but he has many alternative courses of protective action, then it can be shown that for any range of weather probability only one course is optimal. In this case, the decision maker is best served by a statement of the probability of adverse weather. This is done in some places in the U.S.: "Tomorrow there will be a 20% chance of rain, increasing to a 60% chance the day after." But it cannot be achieved entirely without cost, since both meteorologists and users may have to be educated to think in these terms.

In Thompson's study it was estimated that about 40% of the total possible gains in economic value of forecasts could be achieved by such "operational improvements," and 60% by scientific advances. Due to lack of comparable verification data we have been unable to include similar calculations here, but the U.S. study and a smaller Australian study [Mason (1977)] provide grounds for expecting that similar gains could be achieved nation-wide in the Australian tertiary sector. (It is interesting to speculate how the Air Navigation Regulations could best be altered to take advantage of probabilistic forecasts.)

## *6. AN ECONOMIST LOOKS AT THE WEATHER FORECASTING INDUSTRY*

In the course of the survey questions were raised about the total value of weather forecasting (beyond the marginal value of improvements) and the economics of its provision. This section speculates on the structure of the weather forecasting industry, given the evident value to the economy of the improved service. An appraisal of weather forecasting services around the world results in the realisation that in every country with a large weather service the service is government-operated. Is this merely an historical accident and coincidence, or is there a reason for it - a process whose end result has been government-run weather services?

With the Bureau of Meteorology's huge investment in data gathering, processing, and disseminating, no private sector could possibly start in serious opposition today. But a hundred years ago the main requirement of a service was a group of people to collect and send in daily data. In the U.S. the National Weather Service began privately in several areas, was taken over by the Army Signal Corps, and after a few years became a civilian government department. From the history of the service [Whitnah (1961)] the process seems to have been aided by the nature of weather information, which exhibits jointness in consumption and a degree of non-exclusivity: it is hard to sell information exclusively, since it can be shared at no cost, and the only incentive felt by the buyers not to pass on the information is that they have paid for it and the potential sharers have not. (It is this "public good" nature of weather forecasts which has justified government provision of the weather service, as the government provides defence and public health facilities.) In Australia, meteorological observation has been government-sponsored almost from the first [Gibbs (1975)].

It occurred to the author of this paper that another reason for government-run weather services might have been the government's ability, through legislation, to reduce its common law liability for inaccurate forecasts. The author speculated that aggrieved users of incorrect weather forecasts might, last century, in the absence of malpractice insurance, have sued (or at least threatened to sue) the private forecasters, and driven forecasting into the arms of government. Unfortunately for this thesis, no records of any such suits have been found. In fact it seems likely that so long as the forecaster exercises diligence and skills in attempting to predict "Acts of God", he will have discharged his contractual obligations, even if the forecasts prove wrong [Mayer (1979)].

In the U.S. in recent years, many medical practitioners (who also might be considered as providers of imperfect information) have been sued for malpractice, and all are now obliged to carry liability insurance against such suits. From limited enquires of U.S. private weather forecasters, it seems that some of them are aware of the possibility of malpractice suits, and that not only these forecasters but also radio and television stations using the forecasts have taken out liability insurance cover [Geise (1979)]. It would be instructive to know how the premiums are calculated.

Private forecasting in the U.S. is a burgeoning industry. Forecasters do not so much compete with the U.S. National Weather Service, as augment its data with more local data, and predigest some of this data to meet more readily the needs of the clients. In particular, it is likely that through consultation they provide close to "sufficient" weather information [Nelsoh and Winter (1964)] for each client, thus reducing his costs of processing the N.W.S. forecast information. Several recent articles [Anon (1977), Smith (1977), Anon (1978)] have described the industry: over 200 firms, from one with over 65 full-time meteorologists and an annual income of over U.S. $5 million, to one-man outfits. Does the fact that there is a "profitable gap" between public uncertainty and the National Weather Service forecasts mean that the N.W.S. is inefficient? Not necessarily. The N.W.S. is doing its job of gathering, processing, and publishing weather data and forecasts, and it might well be that to attempt to provide what the private forecasters are now providing would lead to an inefficiently large N.W.S. Indeed, so long as the "profitable gap" remains, the arrangement is efficient, and so long as no user of weather forecasts suffers through inability to pay for private forecasts, the arrangement is likely to persist.

It is not clear to what extent there is a similar "profitable gap" in Australia, but the comments of some survey respondents would indicate that, especially in the north, there is room for improvement in the form of presentation of weather data and forecasts. In the absence of demand sufficient to support private forecasters, however, users will continue to rely on the Bureau of Meteorology.

*APPENDIX A*

Australian Graduate School of Management

THE VALUE OF WEATHER FORECASTS
(Questionnaire)

(1) Indicate your general category of business or service (tick one):

| | | | |
|---|---|---|---|
| Construction | ____ | Communication | ____ |
| Wholesale trade | ____ | Finance and investment | ____ |
| Retail trade | ____ | Insurance | ____ |
| Road transport | ____ | Real estate | ____ |
| Railway transport | ____ | Public administration | ____ |
| Water transport | ____ | Health | ____ |
| Air transport | ____ | Education | ____ |
| Entertainment/recreation | ____ | Welfare or charitable services | ____ |
| Restaurants/hotels/clubs | ____ | Electricity and/or gas | ____ |
| Public safety | ____ | Water, sewerage, & drainage | ____ |

(2) Estimate the total annual losses (increased expenditures and/or decreased revenues) due to all weather conditions which adversely affect your business or service on average. Include all losses, even if it is too expensive, or otherwise impractical, to take protective measures against certain weather elements (for example, it may be impractical to provide a separate water supply to alleviate the effects of water rationing in prolonged droughts, or it may be too expensive to provide alternative means of transport during fogs).

$__________per year

MARKS: WEATHER

(3a) Estimate the percentage of your total annual (gross) revenue represented by the weather-caused losses indicated in the answer to question (2):

__________percent

(3b) Estimate the percentage of your total annual taxable income (1976/77) represented by the weather-caused losses indicated in the answer to question (2):

__________percent

(4) Indicate the weather element(s) which most adversely affect your business or service and, if protective measures are, or could be, taken, tick the shortest advanced warning necessary to implement the protective measures:

| WEATHER ELEMENTS (Indicate rain, hail, low visability, draught, high temperature, or other elements) | MINIMUM PERIOD OF USEFUL ADVANCE WARNING (Tick one for each weather element listed) | | | | | |
|---|---|---|---|---|---|---|
| | 1-5 hr | 6-11 hr | 12-36 hr | 2-5 days | 30 days | 90 days |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

(5) Estimate the average annual value of losses which are currently associated with the adverse weather element(s) listed in (4) above, BUT only include losses against which it would be practical to take protective measures if adequate weather information were provided:

$__________per year

(6) Additional comments______________________________

Signature & Organization______________________________

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Table 1

Summary of annual dollar and percentage losses due to adverse weather on the Australian tertiary sector. Figures are overall losses for each industry, the percentage of annual gross revenue, and (in brackets) the percentages from Thompson et al. (1972).

| Industry | Estimated annual gross revenue for 1975/76. | Total losses, irrespective of whether or not protective measures could have been taken against adverse weather. | | | Losses due to adverse weather which could have been protected against, had adequate warnings for appropriate period in advance been available. | | |
|---|---|---|---|---|---|---|---|
| | ($ m) | ($ m) | (%) | | ($ m) | (%) | |
| Electricity/Gas/Water | 2667.8 | 128.1 | 4.8 | (0.2) | 15.1 | 0.6 | (0.1) |
| Construction | 5016.5 | 80.3 | 1.6 | (1.0) | 6.4 | 0.1 | (0.3) |
| Air Transport | 898.6 | 21.6 | 2.4 | (1.1) | 18.0 | 2.0 | (0.7) |
| Other Transport[a] | 2572.5 | 69.5 | 2.7 | (0.3) | 21.2 | 0.8 | (0.2) |
| Communication | 1929.9 | 5.8 | 0.3 | (0.3) | 1.2 | 0.1 | (0.1) |
| Other[b] | 36450.4 | 729.0 | 2.0 | (2.0) | 158.5 | 0.4 | (0.8) |
| Total | 49535.7 | 1034.1 | 2.1 | | 220.3 | 0.4 | |

[a]Road, rail, water, and other transport and storage.

[b]Wholesale and Retail Trade; Entertainment, Recreation, Restaurants, Hotels, and Personal Services

Table 2

Percentages of respondents in each industry who designated the indicated forecast period as the minimum required for an adequate warning of adverse weather.

| Industry | Minimum Forecast Period: Unspecified | 1-5 hours | 6-11 hours | 12-36 hours | 2-5 days | 30 days | 90 days |
|---|---|---|---|---|---|---|---|
| Electricity/Gas/Water | 0 | 15.4 | 7.7 | 53.8 | 15.4 | 0 | 7.7 |
| Construction | 0 | 0 | 0 | 56.3 | 43.7 | 0 | 0 |
| Air Transport | 14.3 | 64.3 | 14.3 | 0 | 7.1 | 0 | 0 |
| Other Transport[a] | 0 | 0 | 25.0 | 41.7 | 25.0 | 0 | 8.3 |
| Communication | 66.7 | 33.3 | 0 | 0 | 0 | 0 | 0 |
| Other[b] | 19.0 | 4.8 | 14.3 | 4.8 | 30.9 | 21.4 | 4.8 |

[a]Road, rail, water, and other transport, and storage.

[b]Wholesale and Retail Trade; Entertainment, Recreation, Restaurants, Hotels, and Personal Services.

Table 3

Ranking by industry of the importance of the weather elements.

| Industry | Weather Elements | | | | | | |
|---|---|---|---|---|---|---|---|
| | Rain | Wind | Temp. | Visib. | Hail | Drought | Snow |
| Electricity/Gas/Water | 1 | 3 | 2 | - | - | 4 | 4 |
| Construction | 1 | 3 | 2 | - | 4 | - | - |
| Air Transport | 4 | 2 | 4 | 1 | 2 | - | - |
| Other Transport[a] | 1 | 3 | 3 | 2 | - | 3 | - |
| Communication | 1 | 1 | 1 | - | - | - | - |
| Other[b] | 1 | 1 | 3 | 3 | 5 | 5 | 5 |

[a]Road, rail, and other transport, and storage.

[b]Wholesale and Retail Trade; Entertainment, Recreation, Restaurants, Hotels, and Personal Services.