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Economic benefits of meteorological services

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There is an increasing need for more rigorous and more broadly based determination of the economic value of meteorological services as an aid to decision-making on the appropriate level of funding to be committed to their provision at the national level. This paper develops an overall framework for assessment of the economic value of meteorological services based on the recognition that most national meteorological infrastructure and services possess the non rival properties of public goods. Given this overall framework for determination of both total and marginal benefits, four main methodologies appropriate for use in valuation studies – market prices, normative or prescriptive decision-making models, descriptive behavioural response studies and contingent valuation studies – are outlined and their strengths and limitations described. Notwithstanding the methodological limitations and the need for a much more comprehensive set of studies for the various application sectors, it is clear that the actual and potential benefits to individuals, firms, industry sectors and national economies from state-of-the-art meteorological and related services are substantial and that, at this stage, they are inadequately recognised and insufficiently exploited in many countries.

1. Introduction

Societal benefits from meteorological services result from the use of the information provided to improve the outcomes of weather- and climate-sensitive human decisions. National welfare is increased by allocating labour, capital and other resources to the production of meteorological services in aggregate, and to particular components of the service, up to the point where the additional benefits just match the additional costs. Over the past century, virtually every country in the world has committed significant resources to the establishment and operation of a National Meteorological Service (NMS), and the benefits derived, in terms of increased community safety and well-being, have been accepted as self-evidently justifying the public expenditure involved. With increasing pressures on national budgets, however, governments throughout the world are now seeking more formal demonstration of the benefits of public funds invested in NMSs. Alternative funders in the private sector, including industry groups, firms and individual consumers, are similarly seeking information on the benefits and costs of meteorological services. A substantial body of literature, based increasingly on collaborative work between the meteorological and economics professions, has developed since 1960 for assessing the benefits of meteorological services at the individual, firm, industry and national levels (see, for example, Gibbs, 1964; Mason, 1966; Maunder, 1970; Freebairn, 1979; Hickman, 1979; Price-Budgen, 1990; Chapman, 1992; World Meteorological Organization, 1994; Adams *et al.*, 1995; Anaman *et al.*, 1995; Nicholls, 1996; Katz & Murphy, 1997a; Anaman *et al.*, 1998; Stern & Easterling, 1999). The purpose of this paper is to review the various methodologies proposed (and used) for measuring the economic benefits of meteorological services. In particular, it evaluates the applicability of the methodologies and available results as a basis for decision-making on appropriate levels of expenditure on the provision of meteorological and related services.

The remainder of the paper falls into four sections. Section 2 provides some general background on the categorisation of meteorological and related services, the role of meteorological information in weather and climate dependent decision-making, and the total and marginal economic benefits derived from the use of the services. The various methodologies proposed for measuring the economic benefits of meteorological services are described and evaluated in section 3. Section 4 reviews some of the estimated benefits reported in the literature and, in particular, comments on the interpretation and applicability of these estimates for making judgements about appropriate levels of expenditure on meteorological service provision. The final section provides a summary and some conclusions.

2. Meteorological and economic background

Meteorological services involve the provision of information on the state of the atmosphere (often subdivided into the overlapping domains of weather and climate, with air quality sometimes considered as a third category) and, to a more limited extent, that of the underlying ocean, land surface and inland surface water. As illustrated in Figure 1, these services can be conveniently considered as made up of five broad groups (Zillman, 1999):

- provision of information on past conditions from the historical record;
- provision of information on the current state of the atmosphere, ocean, land surface and surface water;
- provision of forecasts of future conditions, including warnings of severe weather and climate events, general forecasts for the community at large and for a range of specialised users, and projections of future climate including both seasonal to interannual and longer-term fluctuations and possible human-induced climate change;
- provision of advice on meteorological, hydrological or oceanographic science and its application to community needs; and
- conduct of investigations into specific scientific problems of the atmosphere, ocean or inland waters.

In addition to their categorisation according to the type of information provided, meteorological services are also frequently subdivided, on the basis of major user sector served, into basic and specialised services. Basic services are those made freely available to the community at large, usually through the mass media, in the public interest, while specialised services involve value adding tailoring to the special needs of individual users or groups of users. The World Meteorological Organization (WMO) has distinguished between 'basic' and 'special' meteorological services in the following terms (World Meteorological Organization, 1990):

- *Basic meteorological services*: those services provided by a National Meteorological Service in discharging its government's sovereign responsibilities to protect the life and property of its citizens, to contribute to their general welfare and the quality of their environment, and to meet its international obligations under the Convention of the World Meteorological Organization and other relevant international agreements.
- *Special meteorological services*: those beyond basic services (which) may include the provision of special data and products, their interpretation, distribution and dissemination, and consultation advice.

Weather and climate conditions have pervasive effects on human welfare. Further, and this is the important point in estimating the economic value of meteorological services, the information provided by meteorological services can be used to change decisions in ways which raise human welfare. At a general level, the benefits from the allocation of scarce national labour,

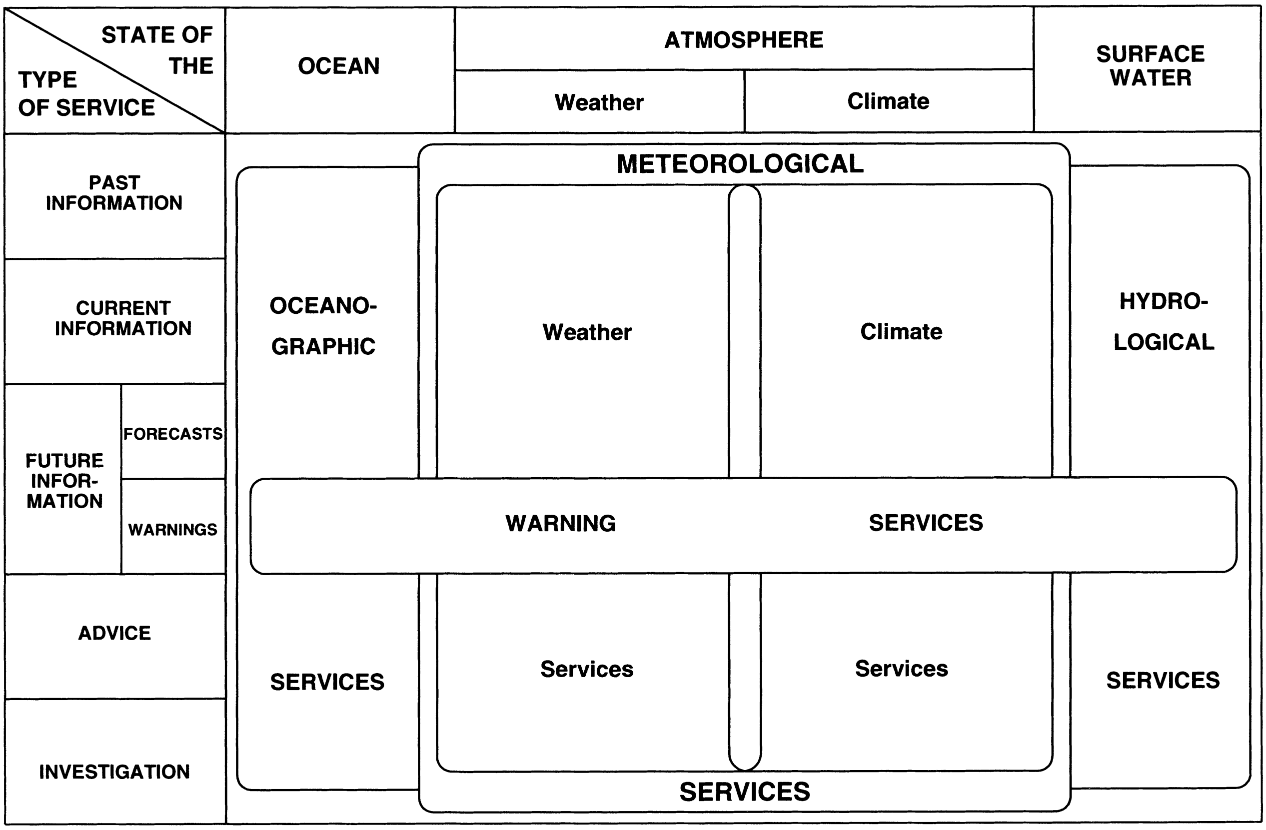

Figure 1. *Categorisation of meteorological and related services according to environmental domain (ocean, atmosphere – including the overlapping domains of weather and climate – and surface water) and type of service (past information, current information, future information, advice and investigation).*

capital and other resources to the provision of meteorological services are given by the increase in human welfare that flows from the better decisions which result where outcomes are weather and climate sensitive. Measures of the economic value of meteorological services include extra profits, lower costs, and assessments of the willingness to pay, by household, business and government decision-makers, for the information contained in the services which they use in formulating and adjusting decisions to yield higher payoffs.

There is no exhaustive listing of either the economic choices and outcomes which are weather and climate sensitive or of those choices which potentially could, or actually do, use information provided by meteorological services. Potential beneficiaries of meteorological services include individuals, households, firms, government organisations and institutions, economic sectors, regions, national economies, the global economy, and future generations. Virtually every sector of every country makes some direct or indirect use of general or user-specific meteorological services. These include agriculture, aviation, banking and financial services, construction industries, disaster management, energy generation and supply, environmental protection, fisheries, forestry, health, insurance, leisure, manufacturing, military, port and harbour management, retailing, transport, sport, urban planning, and water resource planning and management. Typically there is a complex chain of communication, analysis, understanding and decision-making that operates between the provision of meteorological services and the realisation of the potential benefits in terms of better outcomes for decision-makers and for society.

One of the most fundamentally important of all the services performed by NMSs is the operation of the basic national and international meteorological infrastructure. This is required to provide the database for assembly of the long-term climate record for use by future generations as well as for the support of a wide range of real-time operational services with immediate economic and social benefits for society. In economic terms, meteorological infrastructure and weather, climate and air quality forecasts and warnings have non rival consumption or use properties. This means that the economic benefits to society from meteorological services are given by the sum of the benefits reaped by the very many and diverse users of the services, both now and in the future.

An economic framework for evaluating the economic benefits of meteorological services and for determining the allocation of resources to these services can be expressed in terms of a model of total benefits and costs, or a model of marginal benefits and costs which is the conventional economic model of competitive supply and demand determination of prices and quantities. The top panel of Figure 2 presents total costs and total benefits of meteorological services as a function of the level or volume of services. The volume of meteorological services might be measured as units of historical or current data on rainfall, wind, temperature, etc., or in terms of temporal or spatial resolution of model output, or as measures of forecast accuracy and forecast lead-time, or by the scope of the service in terms of effectiveness of communication or tailoring to specific user needs or, more generally, as the quantity and quality of information provided on weather and climate. The total cost function, *TC*, reflects an up-front or fixed cost component *OA* plus an operating cost component which is shown as a convex function reflecting the need for increasing extra inputs per unit increase in the volume of meteorological services. It should, however, be noted that, while some measures of volume (e.g. forecast skill) may require larger and larger increases in resources for small increases in volume, modern technology makes it possible to produce almost limitless increases in volume for other measures (e.g. the number of locations for which spot forecasts can be produced as the output of numerical weather prediction models) with a negligible increase in costs. The total benefit function, *TB*, represents the increase in well-being of decision-makers as the additional and improved meteorological information enables them to make choices which lead to the avoidance of losses and the achievement of gains which would not otherwise have occurred. A threshold volume (measured in terms of skill, availability, etc.) of meteorological services, *OB* in Figure 2, is usually required before weather- or climate-sensitive decisions are changed. The total benefit function, on the other hand, becomes concave and ultimately plateaus as increased amounts of meteorological information lead to smaller and smaller additional benefits in terms of better decisions.

The bottom part of Figure 2 shows the more conventional economic model of the demand for, and supply of, meteorological services. The demand for meteorological services, *D*, is in fact the marginal benefits curve, *MB* (or the first derivative of the total benefits curve in the top part of Figure 2). In the relevant zone for choosing the resources to allocate to the provision of meteorological services, the demand curve is downward sloping because extra information on weather and climate leads to smaller and smaller additional improvements in the results of weather- and climate-sensitive decisions. The supply cost of meteorological services, *S*, the marginal cost curve, *MC* (or the first derivative of the total cost curve in the top half of Figure 2), is an upward sloping function reflecting increasing costs of producing further increases in the volume (quantity and quality) of meteorological information.

The information on benefits and costs in Figure 2 enables determination of the level of resources to allocate to the production and use of meteorological services. The volume of meteorological services Q^* which maximises social well-being is given by the vol-

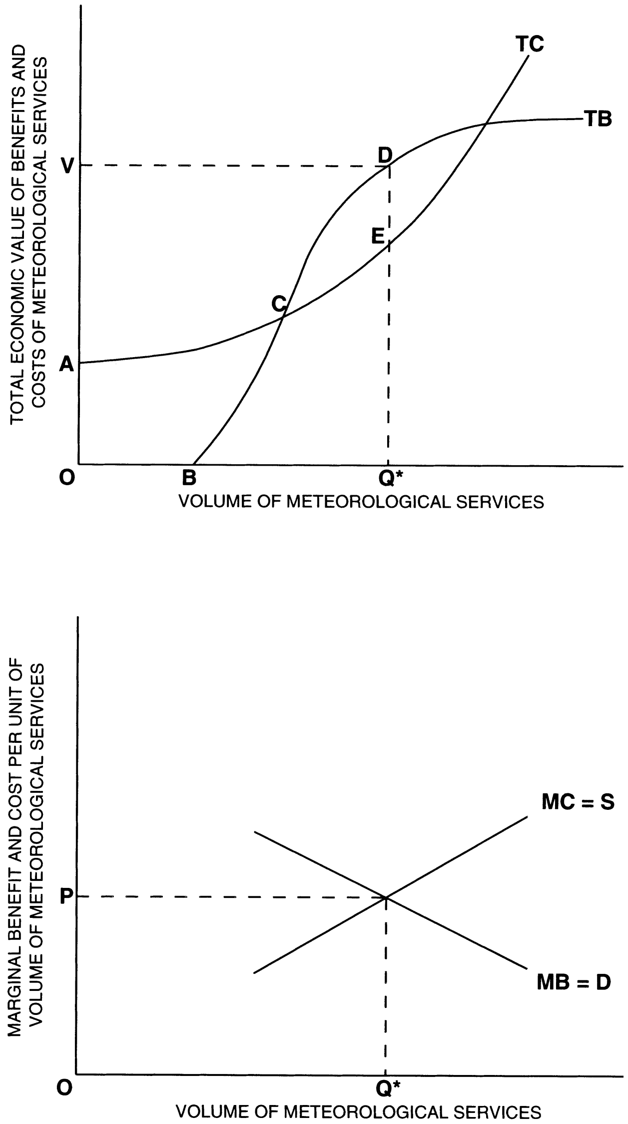

Figure 2. *Total (top) and marginal (bottom) benefits and costs of meteorological services as a function of the volume of services. The curves TB and TC refer to total benefits and total costs respectively. MB and MC refer to marginal benefits and marginal costs which correspond to the demand (D) and supply (S) curves of conventional economic analysis.*

ume where the supply and demand curves equate. It also maximises the difference between total benefits and total costs in the top part of Figure 2. To the right of Q^*, additional resources used to increase the volume of meteorological services add more to costs than to benefits and, in so doing, detract from national welfare. To the left of Q^*, too few resources are allocated to meteorological services in the sense that marginal benefits exceed marginal costs and net gains can be had by expansion.

In estimating the economic benefits of meteorological services, it is important to be clear whether total benefits, as in the top part of Figure 2, or marginal benefits, as in the bottom part of the figure, are being estimated. That is, if the current volume of meteorological services is Q^*, it is important to be clear as to whether total benefits, shown as having the value V in the top part of Figure 2, are being estimated, or whether these are marginal benefits, shown as P in the bottom part of Figure 2. From the perspective of decisions on whether to allocate more or less resources to meteorological services, data on marginal benefits and costs need to be considered.

Most of the meteorological services depicted in Figure 1 have non rival consumption properties. That is, once the information is available, its use by one set of users does not reduce the information available for use by other users. In this circumstance, the social benefits are given by the sum of the benefits of the different users. Figure 3 illustrates the situation for just two users of a particular service (e.g. two individuals using a daily weather forecast or two airline companies using broadcast information on in-flight or landing conditions). The marginal benefit functions (derived as derivatives of total benefit functions) are MB_{A} for user A and MB_{B} for user B. For a given volume of information Q_1, user A values the last unit at P_{A} and P_{B} is the marginal value for user B. The value to society is given by $P = P_{\mathrm{A}} + P_{\mathrm{B}}$. Generalising, when making choices for society about the benefits of meteorological services with non rival consumption properties, the total benefit and marginal benefit functions in Figure 2 should be the sum of benefits for all users as illustrated for the two users in Figure 3.

3. Measurement methodologies

Several techniques have been used to estimate the total benefits, and in some cases the marginal benefits, of meteorological services for particular groups of decision-makers. In terms of the concepts elaborated in Figures 2 and 3, these are the curves TB_i or MB_i, or the values V_i and P_i, where the subscript i denotes a particular group of decision-makers. For convenience, the different methodologies are discussed here under the following sub-headings:

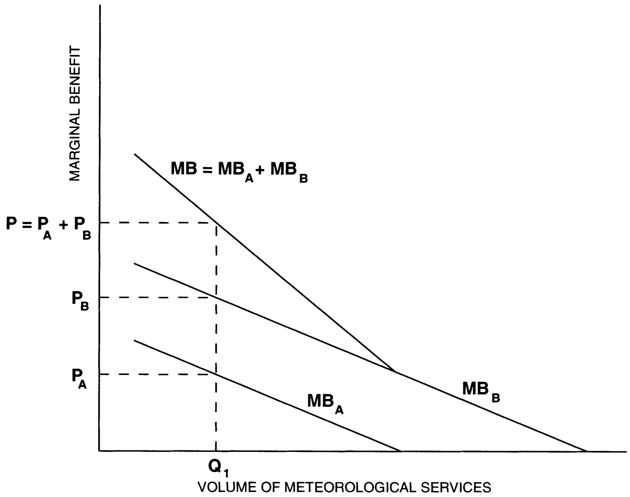

Figure 3. *Marginal benefits of non rival meteorological services as a function of the volume of services. MB_A refers to the marginal benefit for user A, MB_B for user B, and MB is the sum of marginal benefits to both users.*

- market prices;
- normative or prescriptive decision-making models;
- descriptive behavioural response studies; and
- contingent valuation studies.

3.1. Market prices

In several instances, market prices can be used as a measure of the marginal benefits to users of some types of meteorological services. The technique has applicability for those services which have private good characteristics of rival consumption and ease of exclusion. For those services with public good properties of non rival consumption and high costs of exclusion, markets fail. Where the characteristics of non rival consumption and excludability are combined to give mixed public and private goods, market prices may provide some measure of the benefit gained. However, the dominance of public good properties, particularly for the basic infrastructure and for general public forecasts and warnings, limits the applicability of market prices for valuing meteorological services.

In the case of private good meteorological services, such as specialised forecasts for particular users or value adding processing and interpretation of climatological data, customers will purchase the services up to the volume where the marginal value to them equals the price. That is, recorded price and volume fall on the marginal benefit or demand curve, $MB = D$ in the bottom half of Figure 2. Price, then, is the marginal value of the last unit of value added meteorological information to that group of buyers.

There are examples where prices paid by intermediaries in the communication of meteorological services provide a lower bound estimate of the value of the services to final users. For example, in some countries, newspapers, TV and radio pay fees to their NMSs, or to private meteorological service providers, for weather and climate information which they (the media) then publish or broadcast to the community. They all incur direct costs in presenting the weather and climate information – and the space and time allotted to providing this meteorological information have opportunity costs. Media outlets willingly incur these costs on the assumption that readers, viewers and listeners value the meteorological information at more than the costs they outlay, either directly or in putting up with advertisements.

Sometimes a monopoly supplier of private good meteorological services can be imposed on particular users. For example, the NMS or a nominated private firm could be given sole rights to offer and supply specialised services to a specific industry. In this situation, in addition to charging the marginal cost for the value added information, the monopolist also can add an upfront, lump-sum charge. The lump-sum charge plus the user charge cannot exceed total benefits, otherwise – except in the situation of a regulatory requirement to do so – the users will choose not to purchase the value adding services. The extent to which the total charges underestimate total benefits is a difficult empirical problem.

An advantage of market prices is that they explicitly reveal the value users place on, and are willing to pay for, particular categories of meteorological services. However, their applicability is limited by the public good properties of much meteorological information.

3.2. Normative or prescriptive decision-making models

By far the most common set of techniques used to estimate the benefits of meteorological services has been the prescriptive or normative models. Johnson & Holt (1997) and Wilks (1997) provide good outlines and references to applied studies. Simplified optimising decision models for businesses (and also for households and governments, but these have been few) under conditions of imperfect knowledge about weather or climate conditions are solved. The models are resolved for different levels of meteorological services provided. The gain in expected payoffs, including more profits, lower costs and higher utility, are a measure of the marginal benefits of the increased services, that is the MB_i term. The models have been applied to both climatological information and forecast services.

Most reported prescriptive model applications have been for individual decision-makers. In particular, changes in decisions following the use of extra or better meteorological information are assumed not to alter the decisions of others, nor to change the prices of outputs or the costs of inputs. The cost/loss model and the Bayesian rules for using additional information, in this case more and more accurate meteorological information, are common (with excellent descriptions of the procedures and examples in Johnson & Holt, 1997 and Katz & Murphy, 1997b). While most studies have an objective function in the model for maximising profit or minimising cost, several use more general utility functions which recognise risk aversion. Simple one-period decision models have been extended to multi-period problems which recognise the temporal interdependence of decisions. The individual decision-maker models can be, and have been, used to measure the marginal benefits of partial improvements in the accuracy of forecasts as well as the benefits of perfect forecasts.

Results from the individual decision-making model can be extended to represent an industry, region or larger aggregation of users and, in these models, costs of inputs and prices of outputs can be allowed to change as part of second-round reactions to the use of additional meteorological services. Models regularly employed to evaluate the benefits of research and development (R&D), and the distribution of these benefits, can be used (see, for example, Alston *et al.*, 1995). R&D leading to the adoption of new technology or better work and management practices increases output per unit input, or reduces costs per unit output. Similarly, a larger volume (quantity and quality) of meteorological services enables producers to choose decisions which yield more output at lower costs.

By way of illustration, consider a single product market for an agricultural commodity, such as corn, and the use by farmers of skilful seasonal rainfall and temperature outlooks to enable them to make better decisions on, for example, variety choice and the timing and quantities of irrigation and fertiliser to apply. The essential features of a partial equilibrium model for this market are illustrated in Figure 4 and elaborated in the Appendix.

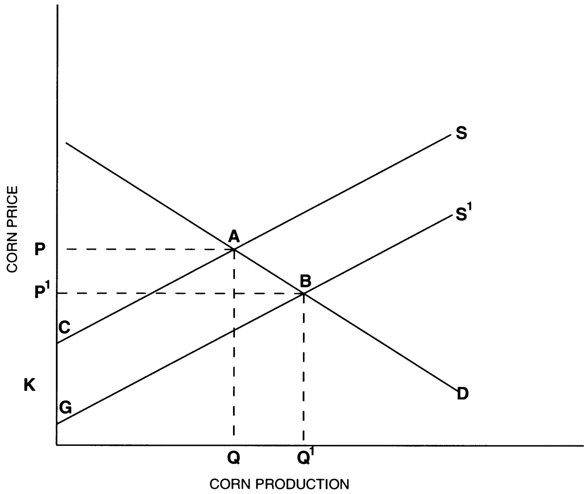

Figure 4. *The benefits of meteorological services for a commodity market such as corn. S is the initial supply curve in a situation of no, or no use of, meteorological services and D is the demand curve with the market clearing price of P and corn production Q. S^1 is the supply curve when the use of meteorological services enables the per unit cost of production to be reduced by K. The new market clearing price and quantity of corn are P^1 and Q^1 respectively.*

The main conclusions which emerge from such partial equilibrium models are as follows. First, much as for the individual decision-maker model, a lower bound estimate of the benefits of meteorological information in improving decision-making sensitive to weather and climate outcomes is given by the cost saving per unit output times the output to which the cost saving applies. This output might be industry output, output from a particular region, or output of identified users of meteorological services. The society gain will be slightly larger to reflect increased producer and consumer surplus (see the Appendix) obtained from an increase in output. Second, the social benefits of better decisions resulting from the use of meteorological services, such as from using a higher volume of meteorological services, will be shared between producers of the products and buyers of the products because the product price falls. In a market context, as opposed to the single producer model where output price is held constant, some of the benefits of a greater volume of meteorological services are passed on to buyers, in the same way as are the benefits of other investments, say in R&D and equipment, which raise productivity.

The market model can be extended, as illustrated in Figure 5 (and as explained in the Appendix), to the case where only some producers effectively use additional meteorological services to improve their decision choices. Here, buyers of the product gain from lower product prices, users of the extra services (the adopters) gain more from the cost reductions than the price fall, the non-adopting producers lose, and there is a net gain for society in aggregate.

Prescriptive models for estimating the benefits of meteorological services have a number of advantages and disadvantages. If the models are realistic simplifications of a complex real world in the sense that decision-makers optimise the chosen objective function, the assumed restraints are realistic, and the meteorological information is used to adjust decision choices as assumed, then the derived estimates of the gains from

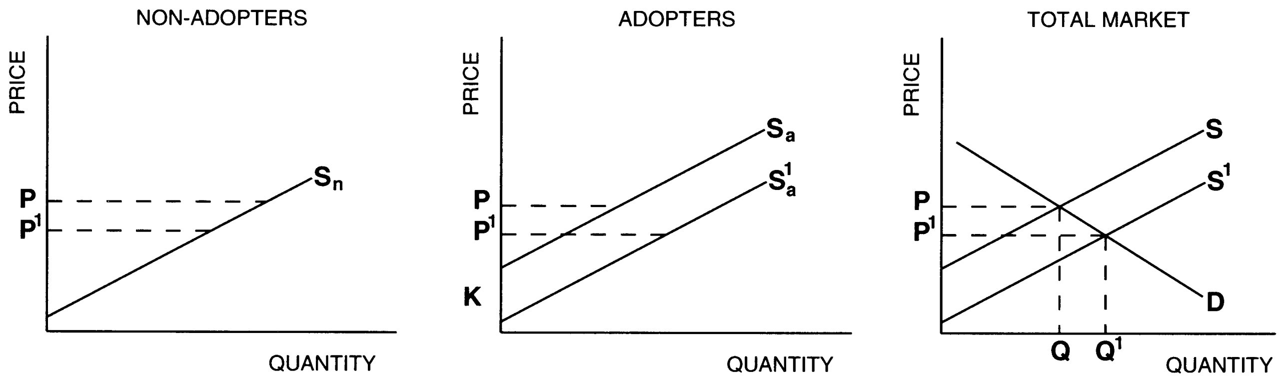

Figure 5. *The benefits of meteorological services in a situation of partial adoption. S_n and S_a are the supply curves for producers in two categories: non-adopters and adopters. These two curves are summed (horizontally) to give the market supply curve S shown schematically in the right-hand panel. Market demand D and supply S determine the initial market price P and quantity Q. The provision of meteorological services lowers production costs for adopters by K per unit output and their supply curve shifts down to $S_a{}^1$. The new market supply curve S^1 is the sum of S_n and $S_a{}^1$. The new market clearing product price, for both adopters and non-adopters, falls from P to P^1.*

better decisions are good estimates of the real benefits of meteorological services by the users. However, realism of the models is a strong requirement – some would say an heroic set of assumptions. In principle, additional detail can be added to any model. Descriptive behaviour studies, discussed below, find that many decision-makers do not respond in the ways predicted by normative models. In particular, many households and firms do not interpret and use meteorological information as assumed in optimising models. In particular, the assumption of zero costs for the information collection, analysis and decision adjustment processes often over-simplifies decision-making. If meteorological information is valuable, as illustrated in Figure 5, in the longer run, competitive forces for survival of the fittest will see the adopters and users of meteorological services dominate the non-adopters. Nonetheless, criticisms of over-simplification of many reported prescriptive models are well made, and more attention needs to be given to realism, including through drawing on the data from descriptive studies.

3.3. Descriptive behavioural response studies

Descriptive behavioural studies can be used to make estimates of the value of meteorological services by inferring values from the observed behaviour of individuals, businesses and governments. User surveys of decision-making – especially those concerned with the use of, and responses to, meteorological information – natural experiments, and (potentially) laboratory experiments and regression methods, have been proposed, and there have been some applications reported in the literature.

One set of studies seeks information about the decision-making processes of individuals and firms, and about how they use meteorological information in these processes. Stewart (1997) provides a good overview, with references to applied studies. Mail, telephone and personal interviews may be used for samples of potential users of meteorological services. Responses are sought on decision choices whose outcomes are affected by weather and climate, what information is used in making these decision choices and, in particular, whether meteorological information is used, and if so, how is it accessed, how is it used to modify decision choices, and what decision changes are made. Further information may be sought on what meteorological information users might like, and how would they use these (with the questions being open-ended), or about any specific proposed changes in services offered.

In special circumstances, natural experiments may be used to estimate the value of meteorological services. These are cases of clearly measured differences in the supply of meteorological services and data on observed changes in behaviour between the different meteorological service states. Craft (1998), for example, uses the natural experiment of a one-year closure of about a half of the meteorological services to the Great Lakes in 1870 to measure cost savings in damage to shipping. Both political and economic considerations caution against conducting such radical experiments. Another example of a natural experiment is provided by observed decision changes during the 1997–98 Australian drought using forecasts based on models of the El Niño–Southern Oscillation phenomena relative to behaviour in previous droughts when no such forecasts were available (Bureau of Meteorology, 1998). This provides the opportunity to evaluate decision responses and the value of extra information resulting from the research, forecasting and communication associated with the El Niño phenomenon.

Regression models may be used to assess the effects of meteorological services on decisions and to measure the value of the services. For example, decisions on enterprise activity levels, or measures of economic performance such as yields, costs and profits, may be regressed on conventional explanatory variables such as resource inputs, prices, measures of technology innovation, and the volume of meteorological services. The approach involves using the regression to estimate the contribution of more meteorological services while accounting for the contributions of other explanatory variables. The regression model approach requires data with sufficient independent variation of the different explanatory variables, including measures of the volume of meteorological services, if the estimates are to have reasonable precision or confidence bounds. At this stage, the absence of data with sufficient variation seems likely to rule out the regression model for all but a few special cases which are close to natural experiments.

The advantages and disadvantages of descriptive studies are often compared with those of prescriptive studies, but they also can be seen as complementary tools. Descriptive studies have the advantage of being based on, and recording, actual behaviour, and therefore they can be considered more realistic. However, in attributing changes in decisions and extra benefits to meteorological services, and to increases in the volume of meteorological services, a common difficulty is that other parts of the decision environment are also changing. Asking questions about decision responses to increases in the volume of meteorological services involves hypothetical situations which make them vulnerable to the same criticisms as those raised against prescriptive studies.

3.4. Contingent valuation studies

An approach sometimes used to estimate the benefits of public goods, particularly environmental services but also defence and the arts, is the contingent valuation method. Here users are asked to nominate the sum they would be willing to pay for a particular level of public good. Although the procedure is somewhat controversial, the contingent valuation method has been used to obtain estimates of the value of meteorological services in studies by Chapman (1992) for the United States, Teske & Robinson (1994) for the United Kingdom, and Anaman & Lellyett (1996) for Australia.

The general structure of the contingent valuation study method is as follows (for more details see Mitchell & Carson, 1989 or Portney, 1994 and references therein). Information is sought from a sample of users of meteorological services, which may be individuals or businesses. To be useful, the sample should be a random sample, and 'representative' samples need to be used with caution. Mail, telephone or direct survey methods may be used. With experience, most now argue that the more costly direct interviewing method is necessary to ensure respondents fully understand the context of the 'willingness to pay' questions and to allow for cross-checking of answers. An artificial, or hypothetical, market situation is created in which users are asked to indicate, in dollars, their 'willingness to pay' for a number of different options. For example, what would you be willing to pay to have access to currently available general forecasts relative to no forecasts; or, if the accuracy of rainfall forecasts for the next season were to be increased by 50%, what would you be willing to pay for this extra accuracy? A number of good practice components of a credible contingent valuation survey can be noted (see, for example, Hanemann, 1994; Diamond & Hausman, 1994). It is necessary to describe and illustrate clearly the optional states being compared, and to ensure that respondents understand the differences that they are being asked to place a valuation on. Greater realism is obtained by indicating the process by which their nominated willingness to pay would be realised, for example by higher taxes or a monthly charge, and by asking respondents to indicate their nominated dollar payment in the context of their income and other expenditure choice options.

Once the answers on willingness to pay for individual users are obtained, the next step is to aggregate these answers for a measure of society's willingness to pay. For those meteorological services with public good characteristics, especially non rival consumption, the strict public good model, as depicted in Figure 3, would sum the willingness to pay by each of the respondents, scaled up by their respective numbers in the population of users. Alternatively, some studies use the estimated median willingness to pay and multiply this by the number of users. The median estimate has support from political theories of the median voter determining election outcomes, including expenditure on public goods, and it has the advantage that extreme individual high and low estimates of willingness to pay are ignored.

The use of contingent valuation surveys to make estimates of the value of meteorological services is likely to remain controversial, as is its use for estimating the benefits for other public goods. The questions are hypothetical and many respondents may not know what they really value about meteorological services and what they would pay. Others recognise that any answer will do and that they cannot be held accountable for the answers given. Besides, there is ample scope for the survey design and interview procedures to bias estimated willingness to pay upwards or downwards. Good practice, and this usually comes at considerable cost, can help to allay some of these criticisms of the method, but it cannot eliminate the reservations.

4. Estimated benefits

Summaries of over 100 studies reporting estimates of the economic value of meteorological services for a range of users are provided in Nicholls (1996), Katz & Murphy (1997a), Anaman *et al.* (1998) and Stern & Easterling (1999). Rather than duplicate these reviews, this section highlights some particular aspects of the studies relating to the procedures used, the estimated benefits reported, and the interpretation of these estimates for the total benefits and marginal benefits of meteorological services.

Most reported studies of the estimated benefits of meteorological services have used prescriptive models of decision-making by individual businesses, and then with a heavy emphasis on agriculture. Very few prescriptive studies have incorporated market reactions. Descriptive studies have been concerned primarily with the use made of meteorological services, and only a few have provided estimates of benefits. In recent years, a number of contingent valuation surveys have been undertaken. Given that many originally fully publicly-funded NMSs now impose charges for some of their services (recovering up to 40% of their total costs of operation in a few countries), and some private sector value-adding services have emerged, the use of market prices becomes more relevant. However, the dominance of public good properties of most meteorological infrastructure and services described in section 2 will require further use of descriptive, prescriptive and contingent valuation methods.

The available estimates of the economic benefits of meteorological services cover a wide range of activities and much of the economy. Most individuals and firms are directly or indirectly affected by weather and climate, and, importantly, at least in principle, most also can use meteorological services to alter decisions to achieve better outcomes as illustrated by prescriptive models. However, the descriptive studies find that a significant proportion of potential users (in many cases more than 50%) do not use meteorological services in decision-making, and this high level of non-use is reflected in a zero willingness to pay found for many respondents in contingent valuation studies.

Nonetheless, it remains the case that very large numbers of individuals and businesses do make extensive use of meteorological services and they receive economic benefits from the improved decision choices which result.

Estimated economic benefits from the use of meteorological services in reported studies vary widely. Many of the estimates per individual or business are low, but many decision-makers are often involved. For example, the Anaman & Lellyett (1996) contingent valuation estimate of the average value of public weather services to Sydney households is just A$24 a year per household, and for a number of agricultural decision predictive model estimates the estimated gains are of the order of A$1 per acre (for example, Wilks & Murphy, 1985; Bosch & Eidman, 1987). But, often, there are millions of households and acres to which these per-unit benefits apply. At the same time, some studies of the benefits of meteorological services for large construction projects, for the airlines (see, for example, Leigh, 1995, and references therein), and for other large businesses report estimates in tens of millions of dollars. For these examples, there is usually only a small number of other actual users of the particular meteorological services.

Despite the number of innovative and excellent studies reported in the literature, available estimates of the economic benefits of meteorological services are too limited for the purpose of deciding whether too many or too few resources are allocated to the production of meteorological services at the national level in most countries. The many case studies of particular value-adding services for specific users based on prescriptive models and market prices are helpful for decisions on those specific value-adding services; in particular, in situations where the marginal benefits and marginal costs of the value-adding services can be compared.

However, fully informed decisions on the allocation of resources for public forecasts and warnings and for the provision of general climatological data where the public good properties of non rival consumption and high costs of exclusion are dominant are difficult on the basis of current estimates. Economic benefit estimates have been reported for only some of the uses and for some of the users of these public good meteorological services. In the context of Figure 3, we might have data for the MB_A curve (i.e. measures of benefits for some users of the services) but we have no estimates for the MB_B curve (i.e. measures of benefits for services and users not picked up in available published studies). Further, we have little idea what share the measured benefits are of the total user benefits, i.e. P_A/P. Given the very diverse uses of meteorological services throughout the economy, compiling the required inventory of the different uses and estimates of the values of these different uses clearly is an enormous task. Inevitably, some uses and users of public good meteorological services will be missed, and, as a consequence, summed estimates of measured benefits will underestimate economy-wide benefits of the services.

For most decisions on whether to add or reduce resources allocated to the provision of particular meteorological services, the key benefit measure is marginal benefits rather than total benefits. Unfortunately, most of the studies published to date focus on estimates of the total benefits of current levels of meteorological services. Of course marginal benefit estimates require some degree of hypothetical reasoning in the case of prescriptive models and some hypothetical questions in the case of descriptive models and contingent valuation surveys.

5. Conclusions

The outcomes of an enormous number of decisions by individuals, businesses and governments are weather and climate sensitive, and potentially the decisions and outcomes can be improved by using currently available meteorological services, with further gains possible if the quality and quantity of services are increased. Normative or prescriptive models clearly indicate the wide range of sources of potential economic benefits of improved, and improved use of, meteorological services. Descriptive studies and contingent valuation studies confirm that many do change decisions with the use of meteorological services and that the information is valued. But these studies also highlight the variety of decision-making methods, the dangers of oversimplification with predictive models, and the fact that not all decision-makers use meteorological services. There is a growing number of examples of market transactions for meteorological services, especially specialised value-adding services for specific users, in which market prices paid indicate significant economic benefits.

Because most meteorological services have public good properties, it will remain difficult to obtain comprehensive estimates of either the total benefits or the marginal benefits of the basic infrastructure, the climatological record or the public forecasts and warnings provided to the community at large. The appropriate benefit measure is the sum of benefits for all users of the public good information. Even though a large number of studies of the economic benefits of meteorological services have been undertaken, they are better interpreted as case studies or anecdotal indicators rather than as a random sample from an unknown population of potential users.

To assist in industry-wide, national and international decision-making on the provision and funding of meteorological services it will be necessary to continue to work with market prices, prescriptive models, descriptive models and contingent valuation methods for estimating the economic value of the full range of meteorological services. The different approaches have different advantages and disadvantages which vary across the spectrum of meteorological services and users. For many users of meteorological services, the different benefit measurement procedures complement each other.

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Appendix. Normative market models

This Appendix develops partial equilibrium, or single product, models for estimating the economic benefits of the use of meteorological information, or of an increase in the volume of information, to increase the average payoff from decisions whose outcome performance is sensitive to realised weather and climate conditions.

Consider an agricultural commodity, such as corn, and the use by farmers of seasonal rainfall and temperature forecasts which enable them to make better decisions on, for example, variety choice and the timing and quantities of fertiliser and irrigation to apply. The initial market situation for the corn market in terms of expected or average longer term demand, supply, price and quantity is as described in Figure 4. Buyer demand is given by the curve D and farmer supply by S, and together they determine the market price and quantity of corn at P and Q, respectively.

Next, suppose the farmers are supplied with skilful seasonal forecasts which they use to change their decisions on variety, fertiliser and irrigation levels. Using individual decision models, perhaps for a representative farmer, but ideally for an appropriate random sample of farmers, it is estimated that, on average, farmer costs per bushel of corn fall by K. Here K is the individual decision-making model estimate of the marginal benefits, MB_i, of using the meteorological information.

Lower costs flowing from the effective use of reliable meteorological information will shift down the farmer supply curve S by the expected cost saving K to S^1 in Figure 4. For simplicity, a parallel downwards shift of the supply curve is assumed. The expected or average longer-term market for corn produced with the assistance of the meteorological services is given by the same demand curve for corn D and the new corn supply curve S^1, resulting in a lower market clearing price P^1 and a larger corn quantity Q^1. Comparing the initial market outcome and the new market outcome permits assessment of the benefits of using the meteorological services for buyers of corn, farmers and society. The lower price benefits buyers. This benefit can be measured by the increase in consumer surplus as area P^1PAB, which also is:

$$(P - P^1)\,(Q + 0.5\,(Q^1 - Q)).$$

Farmers' gain from the lower cost of K per unit output, but market price falls. Since the price fall is less than the cost reduction, farmers gain. This benefit can be measured by the change in producer surplus, or quasi-rent return to farmer land and labour, as area $P^1BG - PAC$, which can be expressed as:

$$(K - (P - P^1))\,(Q + 0.5\,(Q^1 - Q))$$

The net gain for society is thus simply the sum of the buyer plus farmer gain, i.e. the economic surplus gain of:

$$K\,(Q + 0.5\,(Q^1 - Q))$$

which is the area $GCAB$.

Some observations about the measured benefits of meteorological services, and about the distribution of the benefits when second-round responses of product prices are recognised, should be noted. First, producers using the meteorological services continue to gain, but a part of the initial cost savings is eroded by lower prices. Second, buyers become beneficiaries from the fall in product prices, as they are from R&D and business investment generally which lower production costs. The individual decision-making model assuming constant product prices does not pick up this subtle redistribution. Third, for the measure of society benefits from more meteorological services, the scaled-up estimate of the individual decision-making model KQ, where K is the cost saving per unit output and Q is industry output, is a slight underestimate of the actual gain:

$$KQ + 0.5\,K\,(Q^1 - Q)$$

In most cases, the gain associated with the extra product output, $Q^1 - Q$, is relatively small. The main challenge for analysts is to obtain an estimate of K, the average cost saving per unit output across the industry made possible by better decision choice outcomes realised as a consequence of increased and improved meteorological services.

A variant of the market model can be used to assess the distributional effects of meteorological services which are used to advantage by only a subset of firms in an industry or by firms in only one (or several) of many regions. Some firms may not use the services because the extra information is not applicable to them, because they are unable or unwilling to use the extra information, or whatever. A development of the market model to illustrate this situation is given in Figure 5. Suppose corn farmers can be split into two groups: adopters who use additional meteorological information to change decisions which reduce production costs; and, non-adopters who, for some reason, do not, or cannot, use the extra information. Initially the supply of corn by non-adopters shown in the left hand panel is S_n and that of adopters shown in the middle panel is S_a. Total market supply is given in the third panel by the (horizontal) summation of the supply by non-adopters and adopters as $S = S_n + S_a$. Against market demand D, initial period market price and quantity are P and Q, respectively.

With additional meteorological information that enables adopters to reduce their costs by K per unit output, their supply curve shifts down to $S^1{}_a$. Meanwhile, the supply curve for non-adopters remains at S_n. Then the new market supply shifts down to $S^1 = S_n + S^1{}_a$. As a result, with the unchanged market demand D and the new market supply S^1, price falls to P^1, and this fall applies both to adopters and to non-adopters. The adopters win because the cost reduction K exceeds the price reduction $P - P^1$. But, non-adopters who have no cost saving lose from the lower market price. Buyers gain from the lower price.

The simple illustrative models of Figures 4 and 5 can be extended and generalised in many ways. They can be extended to several products and ultimately to a computable general equilibrium model for the economy allowing for second-round behavioural changes to all product prices, input costs and factor returns throughout the economy, or even the globe. Sumner *et al.* (1998) illustrate how various types of trade restrictions and other government policy interventions can be incorporated into models. The idea of Figure 5 can be generalised to many categories of producers, with categories classified by economic, social and other circumstances, and by the level of use of, or changes in the volume of, meteorological services.

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