AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

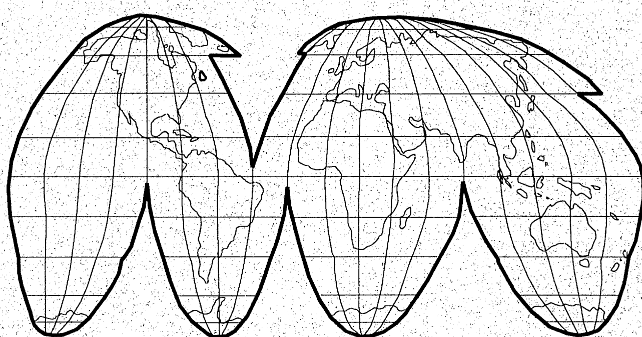
Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Understanding Technical Barriers to Agricultural Trade

Proceedings of a Conference of the International Agricultural Trade Research Consortium



Edited by David Orden and Donna Roberts

January 1997

The International Agricultural Trade Research Consortium

Uncertainty Aversion and Technical Barriers to Trade: An Australian Example

Donald MacLaren

Impediments to international trade are conventionally classified into tariff and nontariff barriers. The substantial set of nontariff barriers impeding trade in agricultural products may be usefully partitioned into a number of subsets, one of which is labelled technical barriers to trade.[1] Within this subset, are health and sanitary regulations. It has been established that, under specific assumptions, there are equivalences between tariffs and certain nontariff barriers, e.g., import quotas. However, these assumptions do not include either market failure in the form of negative externalities, which may appear only after some delay, or uncertainties about the realization of these externalities. Both are prominent characteristics of the situations in which sanitary and phytosanitary regulations are found. Hence, an assessment of the trade effects of these regulations requires non-standard techniques of analysis.

Regulation by a government agency is the favored approach to the control of 'imported externalities' such as exotic crop pests and diseases. Associated with such externalities are possibly low and, invariably, vague probabilities. The probabilities are vague because very often there is no empirical evidence on which to form objective or even subjective judgements of their size. Such 'low probability, high consequence' events, in general, create difficulties for public policy and the policy process (Camerer and Kunreuther 1989). Camerer and Kunreuther review decision processes for such events and draw on examples such as the wearing of seat belts and the siting of hazardous waste plants, to illustrate the alternative theoretical and practical approaches to public policy in the presence of such market failures. In doing so, they consider some models based on the axiomatic approach and others based on practical rules of thumb. Both of these approaches might be usefully applied to sanitary and phytosanitary barriers to international trade as a basis for developing a theoretical framework for analysing such trade policies.

The principal purposes in this paper are first, to provide a theoretical framework for the analysis of sanitary and phytosanitary regulations and second, to evaluate the implications of this framework for trade policy analysis. The institutional context provided by the Agreement on the Application of Sanitary and Phytosanitary Measures of the Uruguay Round [the SPS Agreement] is summarised. In late 1994, the Australian Government was faced with unprecedented requests for bulk imports of cereals, requests that were necessitated by the sustained drought in eastern Australian which reduced grain output. The pragmatic, rules-of-thumb approach adopted by the Commonwealth Government to evaluate the risks of such

[1]The other subsets may be headed quantitative restrictions, nontariff charges, government participation in trade and restrictive practices, and customs procedures and administrative practices (Hillman 1995).

a loosening of quarantine regulations is outlined. Alternative approaches to decision making under uncertainty are discussed, with attention being paid particularly to those theories which have characteristics of special significance for public policy decisions on SPS regulations. An example is provided which illustrates the use of non-additive probabilities as a representation of the decision maker's aversion to uncertainty, i.e., to the vague probabilities of importing potentially harmful exotic pests and diseases. The risk assessment requirement of the SPS Agreement, the lessons provided by the Australian case study, and the results of a model of decision making under uncertainty are brought together, and their implications for trade policy explored.

Aspects of the SPS Agreement

With the implementation of the Agreements of the Uruguay Round, the national sanitary and phytosanitary regulations of the Members of the World Trade Organization [WTO] are now subject to the Agreement on the Application of Sanitary and Phytosanitary Measures. A sanitary and phytosanitary measure is defined as:

> [a]ny measure applied: to protect animal or plant life or health within the territory of the Member from risks arising from entry, establishment or spread of pests, diseases, disease-carrying organisms or disease-causing organisms; (Annex A, 1a).

Under this Agreement, Members have the right to use these measures (Article 2, para. 1) but only to the extent shown necessary by scientific evidence (Article 2, para. 2). Members are encouraged to base their measures on international standards (Article 3, para. 1), although they may set their own, higher standards if there is scientific justification based on an assessment of risk (Article 3, para. 3).

Article 5 of the Agreement is headed "Assessment of Risk and Determination of the Appropriate Level of Sanitary and Phytosanitary Protection." Risk assessment is defined as:

> [t]he evaluation of the likelihood of entry, establishment or spread of a pest or disease within the territory of an importing member according to the sanitary or phytosanitary measures which might be applied, and of the associated potential biological and economic consequences; or the evaluation of the potential for adverse effects on human or animal health arising from additives, contaminants, toxins or disease-causing organisms in food,
> beverages and feedstuffs. (Annex A, para. 4).

The appropriate level of sanitary and phytosanitary protection is defined as:

> [t]he level of protection deemed appropriate by the Member establishing a sanitary or phytosanitary measure to protect human, animal or plant life or health within the territory. (Annex A, para. 5). This definition is sometimes abbreviated to the 'acceptable level of risk.'

In essence, Members are obliged to undertake a formal risk assessment, paying particular attention to scientific evidence, environmental conditions, quarantine treatment, economic factors including losses from production and costs of eradication, and negative trade effects (Article 5, paras 2-5). It is recognized that relevant scientific evidence may not always be available and provisional measures may be adopted. However, there is an obligation on Members to obtain the necessary data in order to complete an objective risk assessment (Article 5, para. 7).

Pest Risk Analysis

The Australian Quarantine and Inspection Service [AQIS] is responsible for administering the conditions under which imports of plant material enter the country. These conditions are determined partly by the Quarantine Act 1908 and the framework provided by the International Plant Protection Convention [IPPC] (Phillips et al. 1994). The IPPC defines a quarantinable pest to be "[a] pest of potential national economic importance to the country endangered thereby and not yet present there, or present but not yet widely distributed and being actively controlled." (Phillips 1994, p. 7). A pest is defined as "any form of plant or animal life, or any pathogenic agents, injurious or potentially injurious to plants or plant products" (Phillips 1994, p. 7). Using the IPPC framework, AQIS classifies imported seeds into: those which are prohibited under the Quarantine Act 1908; those which are restricted, i.e., importable under conditions determined by AQIS; and those which are unrestricted, although still subject to accepted plant health standards.

The information required to undertake a formal risk assessment analysis of a potential quarantinable pest is: first, to determine whether the particular exotic pest is present in the imported material; second, whether the pest will survive quarantine inspection; and third, whether the pest will establish and spread. Usually, this type of information is not available because it is difficult to acquire in the absence of accidents or comparative international studies which could provide data. Therefore, in 1994, in the face of increasing demands by end-users of bulk food and feed cereals, AQIS had to make an assessment of the previously unknown risks involved in permitting such bulk imports and did so by commissioning scientific research. At the same time a Grain Import Task Force was established to consider the evidence and to process requests for import licenses.

The objective of the Pest Risk Analysis [PRA] which was undertaken in late 1994 for AQIS was to establish the size of the risks involved in the bulk importation of specific grains from Canada and the United States [US]. The approach taken was: first, to identify the exotic pest groups which could be a source of risk in the Australian environment; second, to consider three management protocols for handling each type of grain if it were to be imported; and third, to estimate probabilities of various combinations of pest groups and management protocols. No attempt was made to undertake an economic cost-benefit analysis.

First, the pest groups were identified as i] seed-borne diseases and storage pests, ii] weed species which could be imported along with the grain, and iii] foot and mouth disease from untreated feedgrain. For seed-borne diseases, an inventory was compiled of diseases endemic to Australia and of diseases which are exotic to Australia but endemic to potential source countries for grains. For the feedgrains, barley, sorghum and maize, it was found that in the exotic category there were 2 bacteria, 21 fungi, 4 viruses and 2 storage pests (Phillips 1994). For weed seeds, there were two potential sources of risk: the seeds may carry diseases harmful to cultivated crops; and they may establish and spread, so displacing native vegetation. Around thirty weeds not present in Australia but found in the grain-growing areas of the US and Canada, were identified (Phillips 1994).

Second, a qualitative .assessment was made of the risks under three management protocols. These protocols were: *P1* – steam treatment (95°C for ten minutes) of grain in the metropolitan area before rural delivery, this is a strategy for which there is no previous commercial experience for the volumes of grain involved; *P2* – cracking (kibbling) of grain in the metropolitan area before rural delivery; and *P3* – direct delivery of unprocessed grain to the feedlots where the grain is steam pelleted at 95°C-97°C for 30-45 minutes (Phillips et al. 1994). The issues of concern with respect to risk are summarized in Figure 1.

Third, an assessment was made of the factors which might affect the probabilities of pests being introduced and becoming established. Pests were identified as air-borne (e.g., fungal and rust spores), seed-borne (e.g., mosaic viruses) and soil-borne (e.g., viruses). For example, in the case of a seed-borne disease some assessment is necessary for the following events: "pathogen present in the seed, seed establishment, disease establishment on the host and transmission to other hosts. Each of these has a probability of occurrence but often few data are available on key events" (Phillips et al. 1994). Putting together the range of pests and weed groups for each grain, the economic significance of each grain to Australia, and the risks involved in each protocol, enabled a range of probabilities to be established. These are summarized in Table 1.

With respect to the source and type of grain, the risk was lowest for Canadian barley and highest for US maize. For example, taking Stewart's disease on maize (*Erwina stewartii*), Phillips et al. reported the following probability estimates. For the event: 'rate of seed infection' the probability was estimated to be 0.8; for 'seed establishment' the figure was 0.01; for the event 'disease establishment on the host' estimated probability was 0.0007; and for 'transmission to other hosts' estimated probability was 0.01. Based on a spillage of 500 kg of maize from a 30,000 tonne shipment, the chances of the disease establishment was estimated to be 0.224. With respect to management protocol, *P1* provides the lowest risk and *P3* the highest.

The PRA not only established absolute qualitative ranges of probabilities (Table 1) but also established comparative quantitative ranges with respect to other quarantine risks. For example, it was found that the potential risks from grain spillage under *P3* might be as much as seventeen times greater than the risks from contaminated seed imported under the unrestricted category. It was also concluded that the risks of quarantinable pests being brought in legally by travellers were not negligible but were small in comparison with the potential risks from bulk imports of grain. These comparisons illustrate the point made below, that decision makers' preferences are more clearly formed in comparative situations.

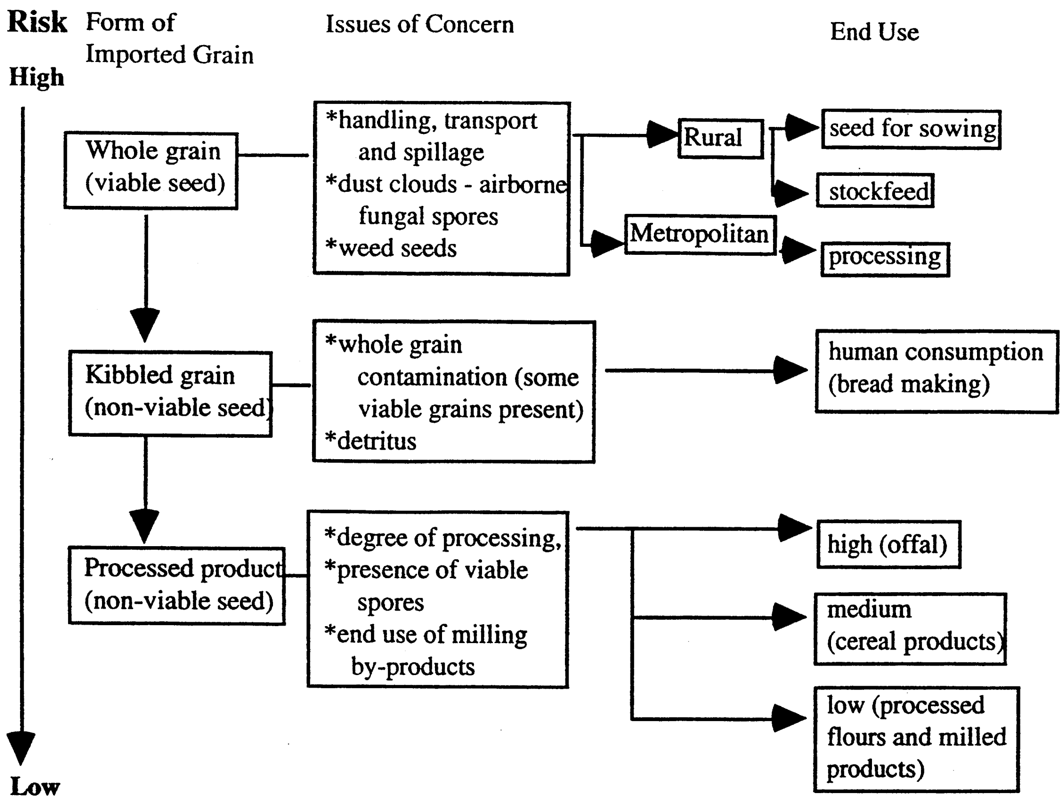


Figure 1. Sources and ranges of risk.
Source: adapted from Phillips et al. (1994, p. 24)

Table 1. Level of risk from pests and weeds[a]

Management Strategy	Level of Risk			
	Barley	Sorghum	Wheat	Maize
P1[b]	L[c]	L	L	L
P2	L	L	M	M-H
P3	L	M	M-H	H

a – Risk is measured with respect to the range of pests and weeds for each cereal and with respect to the economic significance of the crop.
b – For a definition of each Protocol, see the text above.
c – L, Low risk; M, Medium risk; and H, High risk.

Source: Phillips et al. (1994, p. 30)

On the basis of the scientific and judgemental evidence provided by the PRA, AQIS implemented protocol *P3*. There was an outcry from the Grains Council of Australia on behalf of domestic grain growers because of their perception of the risks from spilled grain. This anxiety was justified given one of the conclusions by Phillips et al. (1994, p. 32): "[o]verall these data indicate that there may be a significant weed risk by the spillage of grain along the transport route if spillage is not detected and cleaned up." After there was evidence of grain spillage from covered trucks in rural areas, the Commonwealth Government passed legislation which restricted movement of grain to sealed tankers and, in rural areas, banned on-site processing by end-users unless steps were taken to control dust clouds. However, even with these additional restrictions, grains growers remained cautious about the ability of AQIS to monitor and to quarantine exotic pests and diseases imported in bulk shipments of grains from Canada and the US.

Uncertainty Aversion

A government considering a decision to loosen its quarantine regulations on a previously banned imported agricultural product, e.g., bulk grain, is faced with the uncertain future outcomes of that decision on the domestic environment. It is also faced, of course, with affecting domestic markets for grains and for products which use grains as intermediate inputs. However, neither this aspect nor the political economy dimension of policy (e.g., that of favoring one group of producers over another) is the focus in this paper.

The decision problem facing the government may be formulated in the following way. There are three primitive concepts, namely, consequences, acts and states of nature. **Consequences** (or outcomes or payoffs) may be thought of as the welfare or utility of the decision maker. In the context of import regulations, and in the absence of political economy considerations, it is social welfare rather than private welfare which measures consequences for the government as decision maker. **Acts** are the possible decisions which the government can choose to make. Corresponding to every act, there is a subset of the set of consequences, the particular consequence depending on the actual state of nature which occurs. The set of **states of nature** is assumed here to be finite. In summary, acts are functions from the set of states of nature to the set of consequences (Karni and Schmeidler 1991). In order to determine which act to choose, it is necessary to define a preference relation over the set of acts. A preference relation is defined as:

> a binary relation, $\succsim$, on A [the set of acts] that is (i) complete, i.e., for all $a, b \in A$ either, $a \succsim b$ or $b \succsim a$, and (ii) transitive, i.e., for all $a, b, c \in A$, $a \succsim b$ and $b \succsim c$ imply $a \succsim c$ (Karni and Schmeidler 1991).

This relation requires an evaluation of the consequences of each act together with a judgement about the realization of these consequences.

One of the foundations of rational choice in non-deterministic situations is the assumption that it is possible for the decision maker to separate preferences about consequences from beliefs about states of nature.[2] In particular, in subjective expected utility theory [SEU], the individual's beliefs about uncertain events is represented by a unique and additive subjective probability distribution defined over the set of all possible states of the world; and preferences over consequences are linear in these probabilities. The decision maker is then assumed to choose the act for which the subjective expected utility is largest. Let $S = \{s_1, s_2, \ldots, s_n\}$ be the finite set of all possible states, $x(s)$ be the consequence of an act $X \in A$ if state $s \in S$ occurs, and $p(s)$ be the subjective probability of state s. Then an act X is represented by the vector $(x(s_1), p(s_1); x(s_2), p(s_2); \ldots ; x(s_n), p(s_n))$ (Camerer and Weber 1992). Consider another act $Y \in A$. Then in a comparison between acts X and Y, either X is strictly preferred to ($\succ$) Y, X is indifferent to ($\sim$) Y, or Y is strictly preferred to X. The comparison is based on the evaluation of

$$\underset{a \in A}{SEU(a)} = \sum_{s \in S} p(s) U(a(s)) \tag{1}$$

where $U(a(s))$ is the utility associated with the consequence of act a when the state of nature is s.

Despite the widespread acceptance of SEU as the 'normative benchmark' for rational decision making in the absence of certainty, a number of results in experimental economics, beginning with the Ellsberg paradox (Ellsberg 1961), have challenged the assumptions upon which SEU is based and have shown it not to be a good descriptive theory (Kelsey and Quiggin 1992; Camerer and Weber 1992; Karni and Schmeidler 1991). Of these assumptions, only one will be highlighted in what follows, namely, the way in which beliefs are represented by probabilities.[3]

A distinction is usually made between risk and uncertainty: under risk, it is assumed that the decision maker can assign known, objective probabilities to the states of nature, i.e., beliefs can be represented by a single probability distribution; under uncertainty, it is assumed that the decision maker is unsure of the probability distribution, i.e., the probabilities of the states of nature are said to be vague or ambiguous (Camerer and Weber 1992). Hogarth and Kunreuther have taken the typology further by suggesting that knowledge of outcomes should be classified as precise, ambiguous or none (ignorance). With probabilities being classified in the same way, this gives a 3 x 3 table, with the cells ranging from precise-precise to

---

[2]This separation has been criticized as inappropriate, for example, by Nau. Such separation depends on the validity of the independence/sure-thing axiom, the experimental evidence for which suggests that decision makers consistently violate such assumed behavior. Moreover, in practice, what is observed is the product of probability and utility, thereby masking what might be state-dependent utility.

[3]It will be assumed in what follows that governments and the community are prepared to trade-off potential damage to the rural environment from imported grains. In practice, such trade- offs may not be entertained, i.e., dollars and environmental damage may be part of the government's multi-attribute utility function but may enter in a way which does not permit the trade-off. For a discussion of this point in public policy making, see Camerer and Kunreuther.

ignorance-ignorance. Their research focused on the latter but in this paper, it is more appropriate to consider the ambiguous-ambiguous case.

Ellsberg showed that his subjects had a preference for betting on known rather than on less well-known probabilities in a way which was inconsistent with the assumed behaviour in SEU theory. In SEU theory, this distinction makes no sense because all subjective probabilities are known to the decision maker. Ellsberg's contribution was to show that decision makers do distinguish between known and unknown probabilities. For example, in his '3-colour problem' a decision maker is faced with an urn containing 30 red balls and 60 balls which are either black or yellow but in unknown proportions. The decision maker is offered a set of gambles in which the amount won is \$100 and the amount lost is \$0. The four gambles are: A — win (W) if a red ball (R) is drawn; B — win if a black ball (Bl) is drawn; C — win if a red ball or a yellow (Y) ball is drawn; D — win if a black or a yellow ball is drawn. In choosing between gambles A and B, most subjects chose A; but between gambles C and D, most chose D. This outcome violates SEU theory for the following reason. Let $p(R)$, $p(Bl)$, and $p(Y)$ be the subjective probabilities of drawing a red, a black or a yellow ball, respectively. In SEU theory, gamble $A \succsim B$ iff $p(R)U(W) > p(Bl)U(W)$, i.e., iff $p(R) > p(Bl)$. Moreover, $D \succsim C$ implies $p(Bl \cup Y) > p(R \cup Y)$. If probabilities are additive, then $p(Bl \cup Y) = p(Bl) + p(Y)$ ($\because p(Bl \cap Y) = 0$) and $p(R \cup Y) = p(R) + p(Y)$. Hence $D \succsim C$ implies that $p(Bl) > p(R)$ which contradicts the previous conclusion that $p(Bl) < p(R)$ and, therefore, that $A \succsim B$. The conclusion from this experiment is that players exhibited uncertainty or ambiguity aversion: preferring the unambiguous probabilities to the ambiguous.

This experimental evidence is important because in real-world decision making situations, with the exceptions of games of chance, probabilities are often, at best, ambiguous. The ambiguity arises because of missing information which is relevant to the decision being made and which could be known (e.g., the proportion of black and yellow balls in Ellsberg's 3-colour problem). In the context of a government modifying its sanitary and phytosanitary regulations, ambiguity may arise because of the differing opinions of experts about the correct interpretation of the available evidence or about the need to acquire additional evidence. In such a situation, from the perspective of the government as decision maker, the missing information which causes the ambiguity is the information about which expert's belief is correct. Such ambiguity may highlight the limited role of scientific evidence in public policy decision making.[4] Moreover, governments may be sensitive to, and be influenced by, the public's perception of the risks, even though it is known that such perceptions are biased.[5]

More recent results (Heath and Tversky 1991) tend to show that ambiguity aversion is displayed by experimental subjects only under certain experimental designs. For example, if players have some knowledge of the situation with which they are comparing a chance event, they tend to back their own prior (even if vague) beliefs, rather than choose the chance outcome with the unambiguous probability; but they will choose the latter over the former

---

[4]For a critical appraisal of the role of science in the scientific approach to public policy see Formaini, particularly Chapter 5.

[5]Camerer and Kunreuther discuss a number of sources of bias in judging probabilities.

outcome when they have no such personal knowledge. Fox and Tversky conclude that ambiguity aversion can be interpreted as a reluctance by the decision maker to act on inferior or missing information and that such reluctance occurs only when a comparison is being made between two situations with different degrees of ambiguity or familiarity.

The implications for public policy of the results by Ellsberg, Heath and Tversky, and Fox and Tversky seem clear. Because policy decisions involve a choice between the status quo and a change of policy, the results from comparative situations ought to be the more relevant. That is, ambiguity aversion should be observed in real world situations. This appears to be so in those low probability, high consequence situations in which decision makers have limited experience (Camerer and Kunreuther 1989). For example, governments may have a preference for maintaining the status quo because they perceive that the economic and political costs of lost opportunities, e.g., export revenue from beef foregone, are less than the economic and political costs of a mistake, e.g., the importation of noxious pests and diseases with feedgrains. Hence, there can a be status quo bias in public policy decision making in the face of uncertainty caused by an aversion to loss (sometimes referred to as the endowment effect)[6]. Another source of status quo bias is transactions costs, i.e., the cost of implementing a new policy. It is interesting to note in the Australian case described above that the government chose to implement the cheapest Protocol (*P3*) despite the greater risks involved.

If SEU theory is not an appropriate description of uncertainty averse behavior, then neither can it form a sound basis for policy prescription. The characteristics of alternative theories need to be considered. A substantial number of alternative theories exist that are based on assumptions which are thought to be more consistent with some aspects of observed behaviour, although not with all aspects. These theories include, for example: weighted utility theory; rank-dependent expected utility theory; prospect theory; maxmin expected utility theory; models of complete ignorance in which probabilities are replaced with the maximin criterion; regret theory; theories based on a lexicographic ordering; theories based on state-dependent utilities; and theories based on non-additive probabilities.[7]

One of the implications of ambiguity aversion is that subjective probabilities are not additive. If A and B are sets of events with $A \subseteq B$, then non-additivity means that $p(A \cup B) \neq p(A) + p(B) - p(A \cap B)$. "Non-additivity allows $p(A)$ and $p(B)$ to measure likelihood of events (implications of evidence), while $1 - p(A) - p(B)$ measures faith in those likelihoods (weight of evidence)." (Camerer and Weber 1992, p. 348). The axioms of Savage were modified by Schmeidler to incorporate non-additive probability, obtaining in the process Choquet Expected Utility [CEU]. In this theory, probabilities (capacities) are allowed to represent both implication of evidence and weight of evidence.

---

[6]A substantial discussion of status quo bias in decision making is given by Samuelson and Zeckhauser.

[7]Surveys and evaluations are provided by Camerer (1992), Camerer (1995), Camerer and Weber, Harish and Camerer, Karni and Schmeidler, Kelsey and Quiggin, and Ward.

In order to use CEU, the payoffs $U(a(s))$ for each act $a \in A$ and each state $s \in S$ need to be ranked such that $U(a(s_1)) \geq U(a(s_2)) \geq \ldots \geq U(a(s_n))$ and then the following equation is used in place of equation (1) to determine the expected value of an act a:

$$\underset{a \in A}{CEU(a)} = U(a(s_1))p(s_1) + \sum_{i=2}^{n} U(a(s_i)) \left[p\left(\bigcup_{j=1}^{i} s_j \right) - p\left(\bigcup_{j=1}^{i-1} s_j \right) \right]. \tag{2}$$

When the probabilities are additive and the states are mutually exclusive, the term in brackets is $p(s_i)$ and CEU becomes SEU (Camerer 1995).

An Example

Assume it is known that the country from which grain is to be imported has two diseases, d_1 and d_2, which are endemic and which are also not present in the importing country, i.e., they would be exotic diseases, if imported and established. These diseases could be, for example, fungi, rusts, viruses or bacteria but, equally, they could be pests such as insects or weeds. It is also known that a treatment (or management regime) exists which will reduce the chance of these diseases being released into the environment of the importing country, should they arrive with the grain. However, it is recognized that the treatment is not totally effective in eradicating the diseases. The economic analysis conducted on the net benefits and costs of allowing imports to proceed (i.e., the payoffs) would measure social, rather than private, costs and benefits because of the potential negative externality created by any release of these exotic diseases into the environment, the costs of their eradication, and the loss of export revenues from high-quality grain.

Assume that there are four possible outcomes which the government could observe if imports were allowed. These are: $\theta_1 \equiv$ an outbreak of disease d_1 ; $\theta_2 \equiv$ an outbreak of disease d_2; $\theta_3 \equiv$ an outbreak of both diseases; and $\theta_4 \equiv$ no outbreak of either disease. In order to decide whether or not to remove the quarantine barrier to imports, and assuming that it is prepared to trade off dollars for potential environmental damage, the government needs information on the payoffs (net social benefits), $U(a(s_i))$, for each state of nature, i, as well as the probability of each state occurring, $p(s_i)$ $i = 1, 2, \ldots, n$. These payoffs will be determined, in part, by the effect which any established exotic disease may have on the domestic production of grain and/or on other plants. The probability of each state depends: i] on whether or not the disease is imported, which in turn depends on the quality of disease control on shipments leaving the exporting country; ii] on the success of the treatment of imported shipments; and iii] on the interaction of each disease with the domestic environment, e.g., whether or not the natural conditions are conducive to the establishment and spread of the disease should treatment fail to be 100 percent effective for any shipment. Clearly, these probabilities are extremely ambiguous; the scientific community having very little, if any, information on which to determine their sizes because the conditions under which they might be calculated have not been observed before in the importing country.

Mukerji has argued that the axiomatic approach used by Schmeidler and by others in deriving equation (2) has not provided an intuitive link between the knowledge available to the decision maker (his or her epistemic status) and his or her behavior as represented by the use of the Choquet integral. In developing such intuition, he adds another outcome space, Ω, which comprises more primitive elements than the elements of the payoff space, Θ. Associated with each $\omega \in \Omega$ there is a probability $p(\omega)$. There is an "implication mapping," $\Gamma(\omega)$, from the space Ω on to the space Θ which is based purely on the decision maker's subjective knowledge. $\Gamma(\omega)$ may or may not map a primitive outcome ω_i to a single-element subset $\{\theta_i\} \in \Theta$, i.e., to a singleton. Ambiguity is represented by those subsets in $\Gamma(\omega)$ which are not singletons. From the probabilities in the primitive outcome space, Ω, the decision maker is assumed to derive beliefs about the outcomes in the payoff space Θ. The extent to which this can be done unambiguously depends on the extent of the decision maker's knowledge as represented by the relationship between these two sets. Limitations on that knowledge, together with the decision maker's awareness of them, generate non-additive probabilities in the payoff space and provide an intuitive justification for using CEU to evaluate decisions under uncertainty aversion. This framework is sufficiently flexible to allow the decision maker to reduce ambiguity through acquiring more information which may either modify the implication mapping, $\Gamma(\omega)$, or make more precise the elements in the primitive outcome space, Ω, or in the payoff space, Θ.

To illustrate Mukerji's approach, assume that the government has identified a set of primitive outcomes and four underlying more primitive states. Let ω_1 be associated with importing disease d_1 only, ω_2 with importing disease d_2 only, ω_3 with importing both diseases, and ω_4 with no imports of either disease. However, there needs to be a fifth outcome, ω_5, to represent some unforseen event, e.g., some accident between the shipment prior to unloading at the wharf and the grain being used, or a break in the drought which may enhance the environment for the establishment of disease.

The basic components for this problem are shown in Table 2. The probabilities, $p(\omega)$, are assumed to be obtained from a combination of scientific research and subjective judgement. Furthermore, it is assumed that the government infers that an outbreak of disease d_1, (θ_1) is associated with importing disease d_1, (ω_1), the treatment failing and the disease successfully becoming established; and similarly for disease d_2. These are singleton events. The other singleton is θ_4, being the only possible outcome that can be inferred from ω_4. However, the inference from ω_3 is ambiguous because it could lead to any one of the outcomes θ_1, θ_2, θ_3 but the decision maker does not have enough information to know which. Hence, this implication mapping, $\Gamma(\omega)$, is said to be ambiguous because not all outcomes in the payoff space, Θ, are singletons (Mukerji 1995). Recognition that ambiguity alters behaviour is the key difference between CEU and SEU theories because, in the latter, it is assumed that the decision maker can assign an unambiguous probability to the event θ_3. In the former, aversion to ambiguity is captured in the ranking of outcomes and, in general, will lead to a different act being chosen.

The next step is to provide a link between the probabilities defined on the space Ω with those that are defined on the space Θ, the ones directly entering the Choquet sum (equation (2)). To do this, Mukerji defines a belief function which is based only on the information known to the decision maker: $p^*(X) = \{\Sigma_i\, p(\omega_i)|\Gamma(\omega_i) \subseteq X\}$, where $X \in 2^{\{\theta_1,\, \theta_2,\, \theta_3,\, \theta_4\}} \setminus \varnothing$, a function which is not additive in probabilities (e.g., see Table 2, $p^*(\{\theta_1, \theta_2, \theta_3\}) \neq \Sigma_{i=1}^{3} p^*(\theta_i)$. The implication of the belief function is that, if for a particular ω_i, $\Gamma(\omega_i)$ is not a singleton, then the decision maker is assumed to assign his or her belief to the entire set $\Gamma(\omega_i)$ and not just to the individual elements of the set. Applying the definition of the belief function to the outcomes in the payoff space, gives the entries in the final column of Table 2. Because $\Gamma(\omega_1)$, $\Gamma(\omega_2)$, and $\Gamma(\omega_4)$ are singletons, the beliefs associated with them, $p^*(\{\theta_1\})$, $p^*(\{\theta_2\})$ and $p^*(\{\theta_4\})$, are given by $p(\omega_1)$, $p(\omega_2)$, and $p(\omega_4)$, respectively. But because $\Gamma(\omega_3)$ is not a singleton, the belief associated with it is calculated from the belief function as $p^*(\{\theta_1, \theta_2, \theta_3\}) = p(\omega_1) + p(\omega_2) + p(\omega_3) = 0.30$, because the subsets of $\{\theta_1, \theta_2, \theta_3\}$ which satisfy $\Gamma(\omega_3)$ are $\{\theta_1\}$, $\{\theta_2\}$ and $\{\theta_1, \theta_2, \theta_3\}$ respectively. Note that, because $p^*(\{\theta_3\}) = 0$, $p^*(\{\theta_1, \theta_2, \theta_3\}) = 0.30 \neq p^*(\{\theta_1\}) + p^*(\{\theta_2\}) + p^*(\{\theta_3\}) = 0.25$.

Table 2. Basic components of a problem illustrating Mukerji's approach

Ω[a]	$p(\omega)$[b]	$\Gamma(\omega)$[c]	$p^*(.)$[d]
ω_1	0.10	$\{\theta_1\}$	0.10
ω_2	0.15	$\{\theta_2\}$	0.15
ω_3	0.05	$\{\theta_1, \theta_2, \theta_3\}$	0.30
ω_4	0.55	$\{\theta_4\}$	0.55
ω_5	0.15	$\{\theta_1, \theta_2, \theta_3, \theta_4\}$	1

[a]Ω – the primitive outcome space;
[b]$p(\omega)$ – the probability distribution of the primitive outcomes;
[c]$\Gamma(\omega)$ – the implication mapping; and
[d]$p^*(.)$ – the belief function on the outcome space Θ.

The information now missing before the act "allow bulk imports of grain" is evaluated, is the value of the payoffs in each state θ_i. In rank order from the largest to the smallest, let these be c_4, c_2, c_1 and c_3. Mukerji defines a function $\phi(\omega; a)$ which relates the payoffs from an act a with the primitive outcomes $\omega \in \Omega$. For the singleton cases, ω_i (i=1, 2, 4), $\phi(\omega_i; a) = a(\Gamma(\omega_i)) = a(\theta_i) = c_i$. However, for the primitive state ω_3 there is no simple way of evaluating $\phi(\omega_3; a)$ because ω_3 is mapped by Γ to $\{\theta_1, \theta_2, \theta_3\}$. He notes that an uncertainty-averse decision maker might choose the smallest or least favorable payoff amongst the subsets of $\{\theta_1, \theta_2, \theta_3\}$, i.e., $\phi(\omega, a) = \min_{\theta\in\Gamma(\omega)} a(\theta)$. Hence, $\phi(\omega_3; a) = \min_{\{\theta_i\}_{i=1}^{3}}\{a(\theta_i)\}_{i=1}^{3} = a(\theta_3) = c_3$.

Similarly, the payoff associated with ω_5 is given by $\phi(\omega_5; a) = \min_{\{\theta_i\}_{i=1}^{4}}\{a(\theta_i)\}_{i=1}^{4} = a(\theta_3) = c_3$. Finally, the expected value of act a is:

$$\mathrm{E}\phi\ (.;\ a) = \sum_{i=1}^{5} \phi\ (\omega_i;\ a)\ p\ (\omega_i). \tag{3}$$

Let $c_1 = 10$, $c_2 = 15$, $c_3 = 5$, and $c_4 = 20$. Then substituting values from Table 2 into the right-hand side, of this expression gives a value of $\mathrm{E}\phi\ (.;\ a) = 15.25$. It is important to note that the ambiguous outcomes, ω_3 and ω_5, by being given the worst possible payoff (c_3), introduce a bias against the act being chosen ahead of the status quo. This construction reflects the decision maker's lack of information about the sizes of the various conditional probabilities relating to importing diseases, their accidental release, and their subsequent establishment. The matter of their eradication has not been analyzed because the payoff space has been defined in terms of observing an outbreak of disease only.

It now remains to show that $\mathrm{E}\phi\ (.,\ a) = 15.25$ gives the same result as that obtained in calculating the Choquet sum (equation (2)). The Choquet Expected Utility of the act a "allow imports of grain" is calculated from equation (2) as:

$$\begin{aligned} CEU(a) = {} & U(a(\theta_4))p(\theta_4) + U(a(\theta_2))[p(\theta_4 \cup \theta_2) - p(\theta_4)] \\ & + U(a(\theta_1))[p(\theta_4 \cup \theta_2 \cup \theta_1) - p(\theta_4 \cup \theta_2)] \\ & + U(a(\theta_3))[p(\theta_4 \cup \theta_2 \cup \theta_1 \cup \theta_3) - p(\theta_4 \cup \theta_2 \cup \theta_1)]. \end{aligned} \tag{4}$$

Substituting the appropriate values from Table 2 into equation (4), yields CEU = 20[0.55] + 15[0.70 – 0.55] + 10[0.8 – 0.7] + 5[1 – 0.8] = 15.25.[8] This equality between *CEU (a)* (equation (4)) and $\mathrm{E}\phi\ (.,\ a)$ (equation (3)) arises because once the probabilities associated with the singletons are used in the first three terms of both equations, the remaining (ambiguous) probability, (1 – 0.55 – 0.15 – 0.10), is attached to the worst-ranked outcome, in this case c_3, thereby reflecting the lack of weight of evidence and aversion to outbreaks of potentially harmful exotic diseases.

This example has highlighted the type and the amount of information required to undertake a formal economic assessment of the risks of importing and establishing exotic diseases in the face of uncertainty. It has also shown the value of using a theoretical framework in which probabilities are allowed to display weight of evidence as well as implication of evidence. However, in practice governments may not have the patience to wait for the results of such a full-scale analysis. Instead, they may opt for a partial analysis using a simpler approach. Another explanation for choosing a simpler approach is that the computational burden on an individual decision maker is just too great to use some variant of the SEU approach and that it is rational to substitute a heuristic procedure (Camerer 1995). Research in psychology (e.g., that by Tversky et al. 1988) has shown that subjects often use a lexicographic approach in choosing between acts for which there are a number of attributes. In doing so, the binary preference relation ($\succsim$) defined above is replaced by a lexicographic preference relation. Assume that each outcome has only two attributes. Then a lexicographic preference relation over acts may be defined as $a \succsim b$ if either $a_1 > b_1$ or $a_1 = b_1$ and $a_2 \geq b_2$, where the subscript refers to the attribute (Mas-Colell et al. 1995). In the context of the

[8]Mukerji proves the equality of expressions (3) and (4) for the general case.

imported grain example, a government might use a lexicographic function in which probabilities and payoffs are the first and second attributes, respectively. It would compare the probability of the outbreak of an exotic disease (attribute 1) with some maximum acceptable subjective threshold and would then ignore the economic consequences (attribute 2) of permitting imports, should the threshold not be reached. Such an approach approximates reasonably that used by the Australian Government in 1994.

Trade Policy Implications

Trade and environmental issues are very much linked in the presence of sanitary and phytosanitary barriers to trade. For island countries such as Australia, the risks from lowering quarantine standards are real, not only to the natural environment but also to the production and export of 'clean' agricultural products which may hold a competitive advantage and a price premium in international markets. At the same time, the provisions in the SPS Agreement do impose some discipline by obliging governments to assess the need for their own quarantine regulations should they choose to set these regulations at more stringent levels than the recognized international standards.

A summary of the AQIS-sponsored study of a pest risk assessment undertaken in 1994 illustrated one approach to the conduct of risk assessment. It is clear that there is substantial scope for disagreement amongst scientists about the sizes of the probabilities. This case study illustrates the role and responsibility of scientists: their knowledge, their informed judgement in the face of few, if any, experimental or survey results; and the considerable ambiguity inherent in establishing probabilities or beliefs. The Australian Government might believe itself to be justified in choosing the sub-optimal, lexicographic approach to establishing quarantine regulations by identifying only a threshold level for probability and then allowing imports, if the probability arrived at by a consensus amongst scientists is below that threshold. Such a myopic view ignores the wider economic consequences of such an act.

The hypothetical example provided above illustrates, in simplified form, the framework required to undertake an assessment of risk, including the accompanying economic and trade consequences. The benefits from adopting the CEU approach include the following. First, it forces government to evaluate the social costs and benefits, i.e., the payoffs, under different states of nature. In principle, these could be obtained from simulations with a computable general equilbrium model. Second, in assessing this economic information, the decision maker is confronted with the need to consider the trade issues, e.g., the exports foregone in some sectors because of SPS restrictions on imports in others. Therefore, the model is essentially general equilibrium in approach rather than the partial equilibrium approach implicit in the evaluation of only probabilities. As comparative advantage changes through time, the balance of social costs and benefits of various acts will change, thereby altering the choice of the optimal act. And third, the CEU approach helps to identify where the probabilities are vague. It allows the economic consequences of that vagueness to be measured because of the subsequent changes in ranking and, hence changes in the CEU value of any act.

For Australia's trading partners, it may be difficult to mount a convincing argument for more relaxed Australian quarantine regulations for grains or, indeed, for other agricultural products, given the unavoidable state of uncertainty or partial ignorance which abounds with respect to exotic pests and diseases. Nevertheless, the benefits of the CEU approach to assessing the SPS barriers to trade has several advantages over the lexicographic approach, despite the transactions costs of evaluation and implementation. The most important of these benefits is that the CEU approach combines probabilities of physical events with economics in such a way that the choice of the optimal act reflects general equilibrium effects and the optimal act will alter as the underlying comparative advantage of the economy changes. The use of probability thresholds in a lexicographic approach may allow the economic dimension to be ignored. By including that economic dimension through establishing payoffs under different states of nature, less uncertainty-averse behaviour by government may be induced and then sanitary and phytosanitary barriers to trade can be set at safe minima. Risk assessment based on a CEU analysis would then allow the maximum benefits from trade and comparative advantage to be realized.

References

Camerer, C. F. (1992). "Recent Tests of Generalizations of Expected Utility Theory," Chapter 9 in Utility Theories: Measurements and Applications. ed. E. Ward, Dortrecht. Kluwer Academic Publishers, pp. 207-251.

Camerer, C. F. (1995). "Individual Decision Making," Chapter 8 in The Handbook of Experimental Economics. by J. H. Kagel and A. E. Roth. Princeton: Princeton University Press, pp. 587-703.

Camerer, C. F., and H. Kunreuther (1989). "Decision Processes for Low Probability Events: Policy Implications," *Journal of Policy Analysis and Management* 8(4): pp. 565-592.

Camerer, C. F., and M. Weber (1992). "Recent Developments in Modeling Preferences: Uncertainty and Ambiguity," *Journal of Risk and Uncertainty* 5: pp. 325-370.

Ellsberg, D. (1961). "Risk, Ambiguity, and the Savage Axioms," *The Quarterly Journal of Economics* LXXV: pp. 643-669.

Formaini, R. (1990). "The Myth of Scientific Public Policy," New Brunswick: Social Philosophy and Policy Center and Transaction Publishers.

Fox, C. R., and A. Tversky (1995). "Ambiguity Aversion and Comparative Ignorance," *The Quarterly Journal of Economics* CX: pp. 585-603.

GATT (1994). Agreement on the Application of Sanitary and Phytosanitary Measures, *The Results of the Uruguay Round of Multilateral Trade Negotiations: The Legal Texts,* Geneva, pp. 69-84.

Harish, and Camerer (1994). "The Predictive Utility of Generalized Expected Utility Theories," *Econometrica* 62: pp. 1251-1289.

Heath, C., and A. Tversky (1991). "Preference and Belief: Ambiguity and Competence in Choice under Uncertainty," *Journal of Risk and Uncertainty* 4: pp. 5-28.

Hillman, J. S. (1995). Personal communication.

Hogarth, R. M., and H. Kunreuther (1995). "Decision Making Under Ignorance: Arguing with Yourself," *Journal of Risk and Uncertainty* 10: pp. 15-36.

Karni, E., and D. Schmeidler (1991). "Utility Theory with Uncertainty," Chapter 33 in Handbook of Mathematical Economics. by W. Hildenbraud and H. Sonnenschein. Volume 4, Amsterdam: North Holland, pp. 1763-1831.

Kelsey, D., and J. Quiggin (1992). "Theories of Choice under Ignorance and Uncertainty," *Journal of Economic Surveys* 6(2): pp. 133-153.

Mas-Colell, A., M. D. Whinston, and J. R. Green (1995). Microeconomic Theory. Oxford: Oxford University Press.

Mukerji, S. (1995). "Understanding the Nonadditive Probability Decision Model," Discussion Paper No. 9517, Department of Economics, University of Southampton.

Nau, R. F. (1995). "Coherent Decision Analysis with Inseparable Probabilities and Utilities," *Journal of Risk and Uncertainty* 10: pp. 71-91.

Phillips, D. (1994). "Pest Risk Analysis of Seedborne Pests of Barley, Maize and Sorghum from the USA, and Barley from Canada," Bureau of Resource Sciences, Canberra, Nov.

Phillips, D., W. Roberts, and M. Chandrashekar (1994). "Pest Risk Analysis of Seedborne Pests of Barley, Wheat, Maize and Sorghum from the USA and Canada: Part 2," Bureau of Resource Sciences, Canberra, Dec.

Samuelson, W., and R. Zeckhauser (1988). "Status Quo Bias in Decision Making," *Journal of Risk and Uncertainty* 1: pp. 7-59.

Schmeidler (1989). "Subjective Utility and Expected Utility without Additivity," *Econometrica* 57: pp. 571-587.

Tversky, A., S. Sattath, and P. Slovic (1988). "Contingent Weighting in Judgment and Choice," *Psychological Review* 95: pp. 371-384.

Ward, E. (ed.) (1992). Utility Theories: Measurements and Applications. Dortrecht: Kluwer Academic Publishers.