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Clem Tisdell[2]

September 2009

1 A paper presented at the Singapore Economic Review Conference in Singapore, September, 2009

2 School of Economics, The University of Queensland, St. Lucia Campus, Brisbane QLD 4072, Australia
Email: c.tisdell@economics.uq.edu.au

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For more information write to Emeritus Professor Clem Tisdell, School of Economics, University of Queensland, St. Lucia Campus, Brisbane 4072, Australia.

The Precautionary Principle Revisited:
Its Interpretations and their Conservation Consequences

ABSTRACT

The precautionary principle was included in 1992 in the Rio Declaration on Environmental and Development and is a part of important international agreements and documents, for example, the Convention on Biological Diversity. Yet the interpretation of this principle is not straightforward as a guide for environmental policy – a variety of interpretations are possible. This paper identifies and examines various economic versions of the principle. Furthermore, it shows that different economic versions of the principle can give rise to conflicting policy recommendations for resource conservation. In addition, it demonstrates that applications of the principle do not always favour (natural) resource conservation (for example, biodiversity conservation) although the main support for it politically has been on the assumption it does. The principle's potential consequences for biodiversity conservation of the introduction of new genetic material, such as genetically modified organisms are explored.

Keywords

Biodiversity; conservation; climate change; flexibility; learning; precautionary principle; uncertainty.

JEL Codes

Q2; Q28; Q3; H43.

The Precautionary Principle Revisited: Its Interpretations and their Conservation Consequences

1. Introduction

Since the early 1990s, the adoption of the precautionary principle has been strongly advocated as a guide to appropriate environmental policy. In 1992, it was incorporated in the Rio Declaration on Environment and Development. A flow-on consequence of this has been its inclusion in many international agreements and protocols affecting environmental conservation. In this article, it is argued that it is misleading to speak of **the** precautionary principle. This definite term disguises the fact that many different rules or principles can be put forward in advocating precaution. Depending upon what particular rules or measures for exercising precaution are proposed, very different policy consequences can follow. For example, the principle may or may not favour the conservation of natural resources. Although the principle has been strongly supported by conservationists, it only favours the conservation of natural resources and existing biodiversity in particular cases.

The article begins by highlighting the way in which the precautionary principle has been incorporated in international agreements, declarations, conventions, and protocols of significance for environmental conservation. Various interpretations and applications of 'the' precautionary principle found in the relevant literature are identified, put in context and critically assessed. Subsequently, it is shown how different interpretations of the precautionary principle can lead to conflicting policy recommendations as far as the conservation of existing biodiversity is concerned. Then a simple model is introduced to analyse the implications of the introduction of new GMOs and human developed genotypes for the desirability of conserving their existing genetic substitutes. This provides new insights into the rationality of conserving existing genotypes as a precautionary measure.

2. The Incorporation of the Precautionary Principle in International Declarations, Conventions and Protocols.

In 1992, the precautionary principle was included as a guiding principle for environmental policy formulation in the Rio Declaration on Environment and

Development and it has been almost routinely included in subsequent international agreements affecting environmental conservation. Principle 15 of the Rio Declaration states:

> "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

Close examination of Principle 15 reveals that it lacks precision and only provides a very weak guide to environmental policy choices. The nature of the precautionary approach itself is not spelt out. Secondly, although it is said that this approach should be widely applied by States, how widely is not specified. While it is mentioned that the principle should be applied when there are threats of serious or irreversible damage to the environment, no mention is made of how the seriousness of the threat should be determined. For example, how is the social economic loss that might be occasioned by this damage to be assessed? In addition, the scope for reversibility of damages is not always dichotomous (that is reversible or not reversible) because partial reversibility is achievable in some circumstances and the extent to which reversibility can be realized is often time-related. Therefore, the 'in-between cases' involving reversibility are ignored.

The lack of specification of social objectives also constitutes a problem for the application of this principle because these are relevant to deciding whether possible environmental damages are serious or not. Again, a dichotomous view is adopted in Principle 15 about the seriousness of environmental damage: the possible damage is either regarded as serious or not serious (there are no degrees of seriousness) and it is indeterminate as to who will decide whether the damage is serious and how they will decide this. Will this seriousness be decided for example by natural scientists or a select group of these, and what social values ought to be taken into account in determining seriousness?

Just how large the threat should be before preventative action to avoid environmental degradation is required is unclear and the term 'environmental degradation' is imprecise. For example, environmental changes regarded by some individuals as causing degradation may be regarded by others as resulting in environmental improvements. It is also debatable whether society would want to avoid **all** irreversible environmental degradation because human benefits from some such changes far exceed the costs of the environmental loss.

One extreme interpretation of Principle 15 of the Rio Declaration is that it requires precautionary measures to be taken whenever there is **any** threat of irreversible environmental degradation. This has been called the **strong** precautionary principle. A weaker version is that such measures need only be taken if there is creditable evidence that an irreversible threat exists. Judgment is, however, required to decide whether the evidence is creditable and room exists for disagreement. How likely are the threats and how serious they might be is often a bone of contention. Even the theory of logical probabilities, as for example proposed by Keynes (1921), is unable to resolve such matters.

Principle 15 states that the precautionary measures should be cost-effective. One interpretation of this is that these ought to be measures that involve the least cost of avoiding serious environmental damage. However, in some legal interpretations of the principle, the proportionality rule has been invoked, namely that the cost of measures to avert environmental degradation should be proportionate to [balanced against] the benefits to be attained (see Anon, 2009 and reference to *Telstra Corporation Ltd* v *Hornsby Shire Council*, a case decided by Justice C.J. Preston in the New South Wales Land and Environment Court as well as Mohr and Tyrrell, 2006). This appears to entail some rudimentary cost-benefit analysis.

The United Nations Framework Convention on Climate Change (1992) incorporates the precautionary principle in article 3.3. This states:

> "The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To

> achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties."

This is basically the same statement as in Principle 15 of the Rio Declaration. It does not identify what global benefits are to count and how they will be quantified. It mentions cost-effectiveness but it avoids any mention of income distribution issues which are bound to arise in trying to implement cost-effective measures to limit global warming (see for example, Tisdell 2009a, Ch. 11).

The preamble to the Convention in Biological Diversity (1992) notes 'that it is vital to anticipate, prevent and attack the causes of a significant reduction or loss of biological diversity at its source" and "that when there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat". These observations leave open the question of what constitutes a significant reduction or loss in biodiversity (how is that to be determined?) and there is no definite guide about how society should act when there is lack of scientific agreement. The negative statement that lack of full scientific certainty is not a sufficient reason for failing to adopt precautionary measures is very imprecise.

The Cartegena Protocol (2000) has been developed pursuant to the Convention on Biological Diversity. Its purpose is "to contribute to ensuring an adequate level of protection in the field of the safe [international] transfer, handling and use of living modified organisms resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity, taking into account risks to human health, and specifically focusing on transboundary movements." This protocol specifically reaffirms in Article 1 the precautionary approach contained in Principle 15 of the Rio Declaration. The Protocol contains guidelines for risk management and assessment (Article 15 and Annex III respectively) in cases where transboundary movement of living modified organisms is under consideration. Adequate risk assessment and measures to ensure it are seen as an important part of the Cartagena Protocol. However, the provisions only signal general intent and consequently, allow for considerable latitude in their application. Nevertheless, these provisions are an important step forward in applying precautionary principles to environmental policy because they ensure some attention to the need for precautions in the international transfer of living modified organisms.

The precautionary approach also forms part of several other international agreements affecting environmental policies, and the principle has been adopted by the European Commission as a guide for the EU's environmental policies. However, many of the ascribed meanings and interpretations of the precautionary principle found in the literature go well beyond those that can reasonably be inferred from official agreements and international conventions. The principle has become, in many cases, a springboard for favouring particular ethical position supporting environmental conservation or for pre-empting its potential implications. For instance, consider one set of interpretations provided by GDRC (undated). This set is based on a paper by Professor Elizabeth Wilson presented at a conference held in Japan in 1997.

3. Varied Interpretations of the Precautionary Principle and the Choice of Precautionary Measures based on Standard Use of Terms.

1.1. Seemingly positive interpretations of the precautionary principle that are imprecise and not value-free

A mixture of normative and positive interpretations of the implications of the normative principle has resulted in considerable confusion. For example, examining the interpretations identified by the GDRC (undated), only two interpretations appear to be of a positive nature. These are:

(1) **precaution or preventative anticipation** interpreted as "readiness to take action in advance of [full] scientific proof where inaction may be socially or environmentally costly", and

(2) **futurity** which is interpreted as the "recognition that the future is uncertain; but that it needs to be given due weight".

Whether or not the second interpretation is purely positive depends upon how the term 'due weight' is interpreted, but an important element of the precautionary principle is that future events are to a significant extent influenced by present actions. Even in the first case deciding whether inaction is socially or environmentally costly requires value judgements.

1.2. Interpretations that are explicitly value-laden

Additional implications ascribed to the precautionary principle are more problematic. For example, value judgments are added. These include the view that environmental costs be a part of cost-benefit or cost-effectiveness analyses and include "a **presumption** in favour of high environmental quality" [emphasis added by me]. While in social cost-benefit analysis it is important to take environmental costs into account, a presumption in favour of high environmental quality involves a value-bias. A further value-bias is apparent in the interpretation of the precautionary principle which claims that the environment should be awarded "intrinsic value". The ethical and normative nature of 'intrinsic value' is explored, for example, by Gatzweiler and Volkmann (2007).

1.3. Some claims about the policy implications of the precautionary principle need qualification

Two other interpretations identified by Wilson are claimed to be implications of adopting rational precaution. However, they may not always be rational. These are that it implies the "safeguarding ecological space: leaving wide margins of tolerance in environmental capacities" is desirable and that "shifting the onus of proof: imposing a duty of care on those who intend to develop the environment" is a rational precaution. The former rule is relatively open because it does not specify the width of the margins but it may give some support to the use of safe minimum environmental standards. This claimed implication of this principle seems to implicitly include assumptions about how much risk **should** be accepted socially. Thus, apart from its imprecision, a value-assumption could underlie this interpretation. In addition, not all safe minimum standards are rational as can be inferred from my consideration of Bishop (1978) in the next section.

The onus of proof argument is often combined with the view that those who implement environmental or other changes in the availability of commodities should be strictly liable legally for any damages that consequently occur, or that they should be liable if they have not taken sufficient care. Judgment is then required about what constitutes adequate proof or sufficient care. Furthermore, in some jurisdictions and for some types of change, the exercise of care does not rule out strict legal liability, although it may reduce the amount of damages payable (Tisdell, 1993, Ch. 5). These legal strictures all create transaction costs that militate against change, and their application in a blanket-manner is likely to be irrational.

1.4. It is important to consider standard meanings of the words 'precaution' and 'precautionary'

Given that the precautionary principle has been laden with so many value judgements and dubious implications, it seems constructive to return to fundamental analysis of the economic value of exercising precaution in making decisions about resource-use. To do this, I will first consider the standard English meaning of the words 'precaution' and 'precautionary' and then consider analytically the value of adopting precautionary measures for the conservation of natural resources, particularly existing biodiversity.

According to *The Macquarie Dictionary* (Delbridge, 1991) 'precaution' is "1. a measure taken beforehand to ward off possible evil or ensure good results. 2. caution employed, beforehand; prudent foresight" and 'precautionary' means "1. pertaining to, or of the nature of precaution, or a precaution. 2. expressing or advising precaution." Thus, it can be inferred that the use of the terms 'precaution' and 'precautionary' has at least three implications:

(1) the adoption of measures (beforehand) that reduce the likelihood or costliness of unwanted results or outcomes;

(2) the exercise of prudent foresight; and

(3) possible advice to adopt a cautious approach to decision-making.

From this, it is clear that in order to discuss the rationality of deciding to adopt precautionary measures, it is necessary to know what the objective of the decision-maker is. Secondly, one needs to determine how much foresight is prudent (or indeed possible) bearing in mind the collection and processing of information about the future has costs and some aspects of the future may be unknowable. In other words, bounded rationality needs to be taken into account. Third, advising the adoption of a cautious approach can, amongst other things, imply that a risk-averse attitude towards decisions should be adopted and consequently, this may alter the relevant criterion for decision-making under uncertainty. In turn, this can be expected to change the type of precautionary measures that it is rational to adopt. Hence, the rational choice of precautionary measures depends upon:

(1) the objective being pursued;

(2) to what extent it is prudent (or even possible) to gain foresight; and

(3) attitudes towards the bearing of risk or uncertainty.

This will be illustrated for several choice problems involving the conservation of genotypes. A related intellectual issue requiring more consideration is identification of what possible measures can be regarded as precautionary.

4. The Precautionary Principle in Economics and its Application to the Conservation of Natural Resources, especially Biodiversity Conservation.

4.1. Views of economists about precaution and environmental conservation

Introduction of the precautionary principle in economics is usually attributed to Arrow and Fisher (1974). They showed that even when the relevant objective is to maximize **expected** net social benefits and if uncertainty exists about the possible future value of irreplaceable natural resources, conservation of such resources may raise expected gains. In other words, rational precaution tends to favour the conservation of irreplaceable (or difficult to replace) natural resources.

Prior to Arrow and Fisher (1974), Tisdell (1970) introduced the principle in a paper written in 1970 developed from his previous research (Tisdell, 1968, Chs. 5,6 and 7). This paper made it clear that the principle had relevance to a wide range of economic policies and identified circumstances in which precautionary measures are rational and other circumstances in which they prove to be irrational, given that the objective is to maximize expected net benefits. The scope for learning and the future ability to take advantage of new information or improved knowledge were found to be of central importance for decisions about what types of precautionary measures are rational given that expected net benefits are to be maximized.

While these theoretical developments provided new insights into the optimal choice of economic policies, Robert Bishop (1978) building on the legacy of Ciriacy-Wantrup (1968), questioned the relevance of using expected social cost-benefit analysis to guide conservation policies, particularly the conservation of species. Two basic issues were raised:

(1) there is fundamental or irreducible uncertainties about the future value of any species; and

(2) compared to that typically displayed in the application of expected net benefit analysis, greater risk-aversion is desirable.

4.2. Risk-aversion need not favour nature conservation

This led Bishop (1978) to recommend (with some qualifications) the adoption of the maximin gain approach (or the equivalent of a minimax loss approach) based on the use of game theory as a basis for determining the conservation of species. The maximin gain criterion puts heavy stress on the avoidance of possible losses and places a high value on the security of net benefits. When combined with the assumption of Ciriacy-Wantrup (1968) that the cost of conserving individual species at a safe minimum population is low relative to the **possible** benefits from their conservation, it favours the conservation of species. However, the costs of saving **some** species relative to their possible benefits can be high because they need a very large natural area which has a high opportunity cost if conserved. For example, this **may** be so in the case of the orangutan in Borneo (see, for example, Tisdell and Swarna Nantha 2008, pp. 240-241 and references given there). Furthermore, there are also difficulties in determining what is a safe minimum population; while increasing the size of the population of most species adds to their chances of survival, it does not ensure this (Hohl and Tisdell, 1993). Again, if resources for the conservation of species are limited, the safe minimum population approach cannot give an adequate guide to which species should be saved given that all cannot be conserved, that is it fails to solve the Noah's Ark problem (Tisdell, 1990).

It is generally believed that the conservation of existing species is a sound precautionary strategy. However, application of the maximin gain criterion often favours development at the expense of the conservation of individual species. For instance, consider the example given in the matrix shown in Table 1. This is a simple case in which the decision-maker has a dichotomous choice of strategies and in which there are only two possible states of nature. For the human decision-maker, strategy α_1 is to adopt measures to conserve the focal species and strategy α_2 is to opt for development that causes the extinction of this species. There are also two possible states of nature: if s_1 occurs the species is found to have a high value in the future but if s_2 occurs the species is found to have little value in the future. The benefits from economic development are believed to be relatively certain. The values in the body of the matrix shown in Table 1 represent the possible payoffs from this game against nature.

Table 1: A hypothetical game against nature in which the optimal maximin strategy is not to conserve a species.

		Species of high future value	Species of little future value	
		s_1	s_2	
Conserve	α_1	16	2	2
Develop (do not conserve)	α_2	10	10	10*

Given the matrix in Table 1, the minimax gain strategy (identified by an asterisk) is not to conserve the species. This would be so even if the payoff from development was only just a little more than 2. In fact, less risk-averse criteria are more favourable to the conservation of the species. For example, application of the maximax criterion in this case favours the conservation of the species as does the expected gain criterion if the estimated probability of s_1 is high enough. To some extent, it is surprising that the expected gain criterion is more favourable to the conservation of the species than the minimax gain criterion. Nevertheless, this result seems quite consistent with the adage that "a bird in the hand is worth two in the bush".

4.3. Minimax regret as a criterion for environmental conservation

In some cases, the minimax *regret* criterion favours the conservation of a species when the minimax gain criterion does not. However, in the example given in Table 1, it does not. As can be seen from the regret matrix corresponding to the matrix in Table 1 shown in Table 2, the minimax regret strategy in α_2, that is development. On the other hand, if the entry in the top right-hand corner of the matrix in Table 1 is changed to 5 for example, the minimax regret strategy becomes α_1 whereas the minimax gain strategy continues to be α_2. In practice, it seems unlikely that individuals would only consider the value of opportunities forgone and ignore the actual level of benefits that they might obtain when different strategies are adopted.

Table 2: The regret matrix corresponding to the matrix in Table 1. In this case, the minimax regret criterion is unfavourable also to the conservation of the species but sometimes it is favourable to this when the minimax gain criterion is not.

		Species of high future value s_1	Species of little future value s_2	
Conserve	α_1	0	8	8
Develop (do not conserve)	α_2	6	0	6*

From the above discussion, it is clear that whether or not conservation of a species is a rational precaution depends upon attitudes to risk-aversion and the nature of the objective being pursued. Furthermore, increased risk-aversion is not always favourable to the conservation of existing species.

4.4. Risk-aversion is likely to favour strategies to reduce the rate of global warming

On the other hand, risk-aversion is likely to favour adoption of measures to reduce the severity of global warming, such as reductions in greenhouse gas emissions. This is because the possible economic costs of not acting are very high. This problem has a game-like structure similar to that shown by the matrix in Table 3. In this case, two alternative states of nature are possible: s_1, continuing emissions of greenhouse gas as usual does not result in a major economic problem, and s_2, it does result in a major economic problem. Two alternative strategies are considered: α_1, moderate greenhouse gas emission and α_2, continue 'business as usual'. Given the benefits indicated in the body of the matrix, the minimax gain strategy is to moderate greenhouse gas emissions. Even the expected gain criterion will support the choice of this strategy in this case if a major economic loss from 'business as usual' strategy is more likely than a minor loss.

Table 3: Risk-aversion is likely to favour precautionary measures to reduce the rate of global warming and this strategy may be desirable even if risk neutrality prevails.

		Economic cost of GHG emission is low	Economic cost of GHG emission is high	
		s_1	s_2	
Moderate GHG emission	α_1	6	6	6*
Do not moderate GHG emissions	α_2	8	4	4

5. Further Considerations of the Wisdom of Keeping Options Open by Conserving Existing Genotypes – Challenges Posed by GMOs and Other Human Developed Genotypes

5.1. Caution is needed in comparing optimal biodiversity conservation with the stocking of libraries

Following the publication of several papers by Weitzman (1992, 1993, 1998), it has become common amongst economists specializing in biodiversity economics to liken the problem of optimizing the conservation of biodiversity to that of stocking a library. This is done for example, by Goeschl and Swanson (2007) and Di Falco and Chavas (2007). They conceptualize genetic diversity as if it is informational diversity. Such information has current economic value and potential but imperfectly known future value. Taking such matters into account, the problem is to design an optimal library or by analogy, an optimal set of biodiversity. They conclude that taking into account progress in economic theory examining such issues, a greater number of genotypes and greater diversity of these should be conserved to satisfy future options for use than current conditions would imply (Goeschl and Swanson; 2007, p.290). In other words, this would be a rational precautionary measure. The theories which they review rely primarily for their results or expected values of net benefits. This means that uncertainties are not fully accounted for so the practical implications of their conclusion are qualitative. There is not yet a concrete rule to determine which genotypes should be conserved and how many this should be. It is also not clear that maximizing **expected** net social benefits ought to be the guiding rule – it assumes risk neutrality.

A further issue is the extent to which libraries are in fact managed or can be managed in accordance with the proposed general rules claimed also to be valuable in determining the conservation of biodiversity. To what extent, for instance, library collections should be replicated. The failure of libraries to follow similar management rules to those proposed for biodiversity conservation may have lessons for the social management of biodiversity conservation itself. In practice, many libraries may not be managed in a co-ordinated manner.

Furthermore, libraries are not just the repositories of factual information but many hold fictional material designed purely to entertain. By analogy, the economic value of some species resides in their curiosity and observational value to humans, which, as suggested by Bishop (1978), may alter with the passage of time. In addition, individual valuations are influenced by **social** values which can alter as time moves on (see, for example, Tisdell et al., 2006). In such circumstances, values are path-dependent and are not completely endogenous to individuals, as was stressed by Veblen (1934) and Myrdal (1958).

5.2. The optimality of conserving existing substitute genotypes for new human produced genotypes

Kassar and Lassere (2004) show for a special case that even when two species are perfect or very close substitutes and their future evolutionary paths are uncertain, conserving both may be rational and is more likely to be optimal the greater in the uncertainty about their future evolutionary paths. They assume that the goal is to maximize expected net benefits. This result accords with earlier findings about the value of retaining flexibility or keeping options open (Tisdell, 1970). Kassar and Lassere are able to generalise their special case so that it applies to multiple species but continue to assume that their evolutionary paths accord with a particular stochastic pattern.

Although Kassar and Lassere (2004) introduce dynamics into their analysis, traditional economic analysis of the value of conserving biodiversity seems to be based fundamentally on a static conception of biodiversity. For example, it usually assumes that in the period requiring human attention or assessment, that the stock of biodiversity only has the possibility of remaining constant or declining. This seems to reflect the fact that, on the whole, natural evolution is extremely slow and that human actions have caused and continue to cause large reductions in existing biodiversity. Nevertheless, human actions have also ‘added’ genetic material to the natural stock by means of selective breeding and genetic engineering. Therefore, in assessing the genetic stock, we should take account of the pre-existing genetic stock that is lost (or anticipated to be lost), the existing genetic stock that is conserved, and additions to the genetic stock resulting from human efforts which we may designate respectively as sets A, B and C (compare Tisdell, 2005, p. 150; Tisdell, 2009b). Normally an increase in set C (man-made additions to the genetic stock) is, to some extent, at the expense of the pre-existing natural stock

5.3. Human produced genotypes add some genetic possibilities but reduce others

This raises an important issue: although loss of existing genetic material is usually believed to reduce options and therefore, have an economic cost, new human produced genotypes, such as genetically modified organisms (GMOs), open up new potentially valuable possibilities, add to knowledge and can enable further GMOs to be developed. Thus, if one continues with the library analogy, the library may become more valuable when its holdings are at capacity if it reduces its holdings to make way for publications containing new knowledge. Nevertheless, there is still a selection problem involving great uncertainty. Ex post, for instance, it may be found that some of the library materials discarded to make way for new material should have been retained. Furthermore, in some cases, their lost value may never be discovered.

It can be argued that genetic engineering does not add to the available **core** genetic stock because it focuses on recombination of the existing genetic stock, albeit combinations that are unlikely to evolve naturally. If core genetic material is lost as a result of the introduction of GMOs (or as a consequence of other impacts of human activities), this limits the possibilities for future genetic engineering because it reduces the availability of basic genetic building blocks, given our current knowledge. Thus, the opening up of one set of options tends to reduce another set of options and complex economic comparisons are involved that have not yet been effectively addressed by economists.

In many cases, it seems likely that GMOs will lose their ecological fitness at a faster rate than existing organisms for which they are substitutes. This is because GMOs are developed independently of natural environmental forces which over extraordinary long periods of time have shaped natural organisms. Similarly, human selected genotypes that have been in existence for a long period of time may sustain their ecological fitness for longer than GMOs. For example, while Bt genes added to crops may initially be effective controlling insect pests in crops, eventually the effectiveness of this genetic manipulation may decline as a result of natural selection that favours Bt-resistant insects. Nevertheless, Bt crops may remain effective against insect pests for longer than a substitute chemical pesticide to which insects also develop resistance. This observation raises further issues. Given that the ecological fitness of GMOs is of limited duration, to what extent is it important to conserve non-GMOs that are substitutable for these, albeit somewhat imperfect substitutes?

5.4. A model of the benefit from a new GMO in comparison to an existing genetic substitute given that GMOs decline in their ecological fitness with the passage of time

The problem can be considered theoretically by focusing on a simple case. Suppose that a GMO has been developed and that there is a single non-GMO that is a substitute for it. Envisage a situation where the flow of net benefit from use of the GMO as a function of time is indicated in Figure 1 by the relationship ABCF where t_n is the horizon for the decision problem. Assume that the net benefits from the use of the substitute non-GMO are as shown by line DBE. Initially, net benefits from use of the GMO exceed that from utilizing the non-GMO but this relationship is not sustained. Benefits from the non-GMO display sustainability but not those from the GMO – the latter returns slip below those available from the use of the non-GMO after t_1.

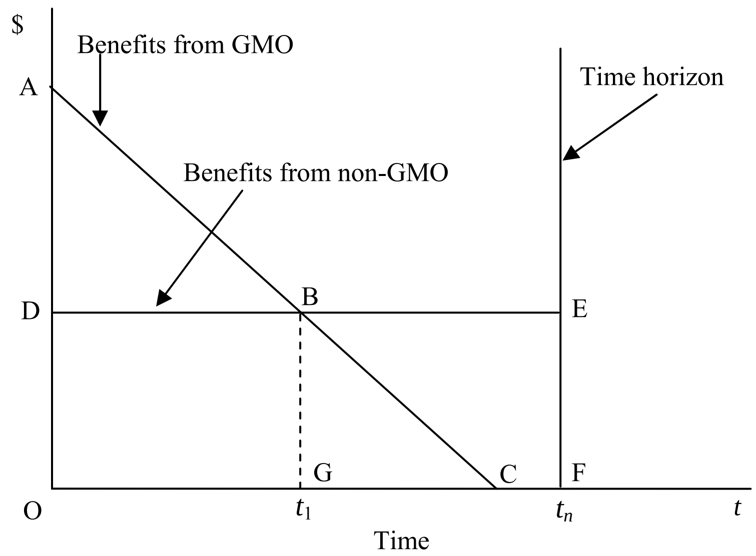

Figure 1: An illustration of the proposition that it can be a wise precaution to conserve a non-GMO substitute for a GMO because the net benefits from a GMO are unlikely to be sustained whereas these from a non-GMO are more sustainable.

Figure 1 indicates that it would be optimal to use the GMO until t_1 but then replace it by the non-GMO **if** it is available. However, its availability at t_1 will depend on the conservation of a viable population of a non-GMO or, in the case of plants (and similar organisms), their storage in a seed bank or a similar facility and this will involve overhead cost.

5.5. Implications of the simple model for the social optimality of conserving existing genotypes

Several interesting implications can be derived from this simple case. If the aim is to maximize the sum of net benefits obtained in the planning period, it will be optimal to use the GMO even when it results in a loss of the non-GMO if the area of triangle ABD exceeds that of quadrilateral BCFE. If the choice is the adoption of the GMO at the expense of the survival of the non-GMO, choice of the GMO is more likely to be optimal, the higher is the discount rate, the shorter the planning horizon and the longer the period for which benefits from using the GMO exceed those which could have been obtained by using the non-GMO.

Nevertheless, an intergenerational equity problem is posed by the above choice **even** if a zero discount rate is used. This is a similar problem to that observed by Dasgupta and Heal (1974). For example, the GMO may be a staple crop, such as rice or wheat. The displacement of non-GMO varieties by a GMO in such cases can cause economic hardship to future generations which might be avoided by conserving substitutable non-GMO varieties. Given the assumed decline in the ecological fitness of a new GMO with the passage of time, the irreversible loss of its existing genetic substitues could severely reduce the amount of food (or other products supplied by crops, such as textile fibres) available to future generations and may impoverish them. However, the conservation of existing genetic substitutes for the new GMO involves upfront costs or overhead costs. If conservation of the non-GMO substitutes for a GMO is an option, then the costs incurred in ensuring the conservation in the period $0 < t < t_1$ need to be compared with the future benefits of doing this which if undiscounted, are equal to the area of the rectangle BGFE. Other things held constant, the discounted value of conserving the non-GMO is less likely to be positive the higher discount rate, the shorter is the planning period and the longer is the period for which returns from the GMO exceed returns possible by using the non-GMO. However, if the returns from the GMO eventually fall below those attainable from the non-GMO, a decision not to conserve the GMO imposes avoidable and possibly severe economic hardship on future generations. The absence of discounting does not remove the intergenerational equity issue. If a high weight is placed on sustaining the welfare of future generations, this will favour conservation of substitutable non-GMOs if a new GMO is introduced or will be a deterrent to its introduction of the GMO if the conservation of a substitutable GMO is costly or problematic. The extent to which precautions should be taken is influenced by the social economic objective to be pursued.

5.6. Uncertainty of benefits from new GMOs favours conservation of their existing genetic substitutes.

In the case illustrated in Figure 1, certainty of the path of returns from the alternative genotypes was assumed. However, many factors are likely to create uncertainties. For example, the rate at which the ecological fitness of the GMO declines is likely to be uncertain as well as its impacts on the genetic composition of other related organisms. This uncertainty is expected to be greater for GMOs than for substitute non-GMOs.

The greater is the uncertainty of benefits from a new GMO (the greater is the possible range of net returns from the GMO), the less likely is the introduction of the GMO to be the optimal social choice, other things held constant. For example, this will be so if a minimax gain strategy is adopted. This is illustrated by the game matrix in Table 3 where payoffs are shown in its body. In this case, there are two states of nature: namely, s_1, the GMO proves to have a high future value or s_2, the GMO turns out to have a low future value. Two possible strategies are considered: α_1, introduce the GMO and eliminate the substitute non-GMO or α_2, do not do this and retain the non-GMO. As can be seen, the minimax strategy is not to introduce the GMO. However, in the example given, the minimax regret criterion favours the introduction of the GMO. A third strategy could be added, namely that of retaining a sufficient quantity of the germplasm of the non-GMO to enable it to be used in the future should the GMO lose its fitness or comparative economic value. This precaution eliminates irreversibility but its optimality depends on the cost and feasibility of conserving the GMO when the non-GMO is adopted. Nevertheless, there will be many circumstances where this precautionary measure is rational. It implies that, as a rule, the introduction of GMOs (and possibly most human improved species of organisms) increases the desirability of conserving their substitute genetypes.

Table 4: An illustration that uncertainty militates against the introduction of a GMO if it results in the loss of a substitute non-GMO

		GMO of high future value s_1	GMO of little future value s_2	
Introduce GMO	α_1	20	6	6
Do not introduce GMO (non-GMO conserved)	α_2	10	10	10*

Note that in the case illustrated in Table 1 application of the minimax criterion (risk aversion) was not favourable to the conservation of existing species or genotypes but the opposite is the case for the example given in Table 4. The rational precautionary measure depends on the structure of the problem, attitudes to the bearing risk and uncertainty and the nature of the aim pursued. For example, it was shown that application of the minimax regret criterion often results in different biodiversity choices to the minimax gain criterion and so on.

The above theoretical argument that a rational precautionary measure when new GMOs are adopted is to conserve existing genetic substitutes for the new GMOs is based on the assumption that GMOs are likely to be wasting assets because they tend to lose their ecological fitness with the passage of time. However, new GMOs may provide stepping stones for the development of additional GMOs that are substitutes for earlier ones. This will tend to reduce the expected benefits from conserving existing genotypes. Nevertheless, because the further developments of GMOs are uncertain, it is still likely to be a wise precaution to conserve existing genotypes that are substitutes for new GMOs, especially if the cost of doing so is not high.

6. Concluding Comments

The precautionary principle has been viewed as an important element of environmental policy since the Rio Declaration of 1992 and is widely believed to be favourable to the conservation of existing natural environments and the current stock of biodiversity including measures to avoid deterioration in these. However, in most legal documents and international agreements the policy implications of the principle are imprecise. Consequently, this principle is not operational without making several additional assumptions. Furthermore, this article shows that conserving existing natural environments and existing biodiversity is not always a rational precautionary measure. Therefore, application of the principle does not always support pro-conservation policies.

It was demonstrated that the choice of a rational precautionary measure depends on a variety of factors such as objectives, attitudes to risk-bearing and the extent which it is rational or possible to be informed about the future. While risk-aversion may favour the conservation of existing genotypes, it does not always do this. The result is sensitive to the type of objective adopted, for example whether the guiding rule is to maximize expected benefit, obtain maximin gain or experience minimax regret. In some cases, the expected gain criterion is more favourable to the conservation of existing geotypes than the minimax gain criterion and conflicting conservation recommendations can emerge from application of the maximin gain and the minimax regret criteria.

Particular attention was given to precautions that ought to be taken when considering the introduction of genetically engineered organisms or human selected genotypes. It was argued that while the introduction of such organisms often leads to the loss of existing biodiversity and reduces options for use of the existing genetic pool, it also opens up new genetic options and learning possibilities. This is frequently characteristic of human innovations. The possibility of one set of biodiversity options being replaced by another set does not seem to have been explored by specialists in biodiversity economics, such as Kontoleon et al. (2007) who report on the current state of the subject. It does, however, emerge from the above analysis that risk-aversion about benefits from human engineered organisms tends to favour policies to conserve existing organisms that are substitutes for new human engineered organisms.

An incidental result from the above analysis is that in assessing the flow of benefits from alternative development strategies, even the use of a zero discount rate, an approach suggested by Ramsey (1928), is inadequate in allowing for the consideration of intergenerational equity (compare Dasgupta and Heal, 1974). This is an additional complication to the lack of any regular connection between the level of the rate of interest and the conservation of the genetic stock (Tisdell, 2009c).

A worrying feature of discussion of the precautionary principle has been the tendency of some individuals to load it with value judgments and to pre-empt its possible implications for environmental policy without considering the logical steps necessary for the conclusions assumed to follow. In most cases, their value judgments are not evident in relevant legal agreements and documents that mention the precautionary principle. For example, one view is that natural environments and existing biodiversity should be imbued with intrinsic values in view of the precautionary principle. This is a normative position that would affect the objective function but it is not an implication of precautionary motives as such. Again, the view that the precautionary principle implies that those wishing to change environments ought to prove that this change does no harm is not necessarily implied by the principle. This procedure may result, for instance, in excess precaution if the standard of proof is very high.

Of course, ecocentrism might favour the conservation of existing genotypes. However, ecocentrism is not an element of the precautionary principle. Again the ‘status quo’ or endowment effect (Knetsch, 1990; Kahneman et al., 1991) will undoubtedly favour the conservation of existing genotypes. Whether such a behavioural bias is rational is unclear but it is a fact of life.

What constitutes a rational precautionary measure is liable to vary with the circumstances involved and one should be wary about drawing hasty general conclusions about what precautionary measures are rational. This is highlighted by conflicting adages in English and presumably in other languages also. For example, the extent to which it is rational to collect information about future possibilities before acting varies with the circumstances. This is apparent from the following English adages: 'He who hesitates is lost' and 'Look before you leap'. The applicability of this advice varies with the circumstances being encountered.

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