Technology change as a policy response to promote changes in land management for environmental benefits

Abstract

A previous study developed a framework for choosing among groups of policy mechanisms for encouraging environmentally beneficial land-use change. The framework highlights that these choices should depend on the relative levels of private (or internal) net benefits, and public (or external) net benefits. Incentive-based mechanisms (polluter-pays and/or beneficiary-pays) and extension need to be targeted carefully to appropriate projects – where private net benefits are close to zero, and/or public net benefits are more extremely positive or negative. This paper focuses on policy mechanisms that alter the net benefits of changing land management, including R&D to develop new technologies, and training to improve the skill of landholders at using existing technologies. These policy options are now treated more comprehensively within the public benefits: private benefits framework. Benefits of technology-change projects can include reductions in the opportunity cost of compliance with environmental programs, increases in the public benefits of a particular type of land-use change, or improvements in private net benefits, resulting in public benefits through greater or more rapid adoption by private landholders. From an environmental management perspective, technology development is most relevant where public net benefits of land use change are positive and private net benefits are negative, but not highly negative. There is a set of projects for which technology change is the only viable alternative to no action, highlighting the importance of technology change in these cases.

1. Introduction

Pannell (2008) presented a framework for selecting policy mechanisms to encourage change in management of privately owned land in order to enhance environmental conservation or natural resource management. The framework is relevant to government programs such as the Conservation Reserve Program, the Environmental Quality Incentive Reserve Program, and the Conservation Security Program in the United States of America; the Rural Development Regulation in the European Union; the National Farm Stewardship Program in Canada; and the Natural Heritage Trust in Australia, which have been created to attempt to encourage such changes.

These programs use a range of mechanisms to encourage change, including education, awareness raising, technology transfer, research and development, regulation, subsidies and other economic instruments. Research has suggested that the benefits from public intervention are likely to be sensitive to the choice of an appropriate type of policy mechanism (Ridley and Pannell, 2005, 2008). In practice, the choice among these possible policy mechanisms is often not very sophisticated. Programs tend to rely primarily on a small number of mechanisms, sometimes as few as one, and not to consider well the appropriateness of their chosen mechanism(s).

Like Gjertsen and Barrett (2004) and Skonhoft and Solstad (1998), the aim of this research is to develop context-specific policy regimes. Compared to those studies, this work considers a broader range of policy mechanism types. It also highlights the over-riding importance of public and private benefits and costs when choosing a mechanism.

Pannell's (2008) framework has been applied successfully in pilots with two regional environmental management bodies in Australia (Ridley and Pannell, 2008), and is now being applied in three further regions. It has also been used to provide advice to government agencies at the state and national levels. However, the treatment of technology change in the original framework was simplistic. In this paper, the framework is modified and used to conduct a more comprehensive analysis of the role of technology change in environmental management on private lands. The paper starts by re-introducing the original framework and then focuses on the impacts and role of technology change mechanisms.

2. Public benefits and private benefits

The best choice of policy mechanism to encourage land-use change depends on the levels of (a) private (or internal) net benefits, and (b) public (or external) net benefits (Pannell, 2008). 'Private net benefits' refer to benefits minus costs accruing to the private land manager as a result of the proposed changes in land management. They exclude transfers and transaction costs that are part of the policy intervention, so that we can compare landholder behaviour with and without the intervention, and can calculate benefit:cost ratios (BCRs) of potential interventions. In principle, private benefits are broader than financial benefits, and include the range of factors that influence the relative advantage of the new land use options (as perceived by the landholders) such as riskiness, complexity, social considerations, personal attitude to the environment, and farming-systems impacts of the land-use practice (Kabii and Horwitz, 2006; Knowler and Bradshaw, 2006; Pannell et al., 2006).

'Public net benefits' means benefits minus costs accruing to everyone other than the person whose land management is to be alterred. They exclude any costs borne by the environmental manager in the process of intervening to encourage the change in land management, again to facilitate calculation of BCRs of potential interventions.

Underlying the framework is a proposed set of rules or principles for choosing whether a particular policy mechanism is appropriate in a particular context. It assists in choosing between broad groups of policy tools, to achieve efficient resource conservation on private lands.

3. Simple framework for static technologies

Policy mechanisms are selected from five broad categories, shown in Table 1. In this paper, I do not address the choice between polluter-pays and beneficiary-pays mechanisms, but instead consider them jointly under the headings of 'positive incentives' and 'negative incentives'. 'Positive' means that land-use change is encouraged, whereas 'negative' means that it is discouraged. In either case, the incentive mechanism used could be either polluter-pays or beneficiary-pays in nature.

Figure 1 shows the allocation of policy tools to projects or interventions depending on the resulting levels of public and private net benefits, as identified by Pannell (2008). This graph is based on static technologies. Technology change is addressed in detail later.

Table 1. Alternative policy mechanisms for seeking changes in management of private lands

Category	Specific policy mechanisms included
Positive incentives	Financial or regulatory instruments[A] to encourage change
Negative incentives	Financial or regulatory instruments[A] to inhibit change.
Extension	Technology transfer, education, communication, demonstrations, support for community network
Technology change	Mechanisms that alter the benefits of land management options, such as strategic R&D, participatory R&D with landholders, provision of infrastructure to support a new management option, and training to enhance the performance of existing technologies.
No action	Informed inaction

[A]Financial or regulatory instruments include polluter-pays mechanisms (command and control, pollution tax, offsets) beneficiary-pays mechanisms (subsidies, conservation auctions and tenders), and mechanisms that can work in either way depending on how they are implemented (define and enforce property rights, such as through tradable permits).

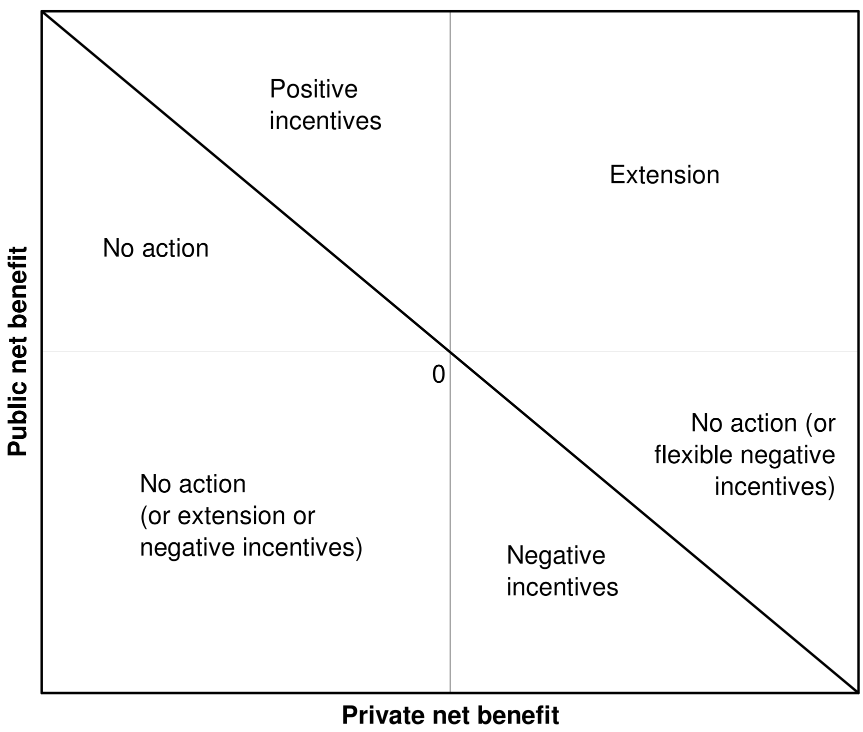

Figure 1. Suggested classes of policy tools for different levels of public and private benefits

It is assumed that landholders will adopt all land-management practices with positive private net benefits, provided that they are able to learn about those practices. Initially, zero learning costs for landholders are assumed. Given these assumptions, the following rules for selecting policy mechanisms are used, as per Pannell (2008).

1. *Do not use positive incentives for land-use change unless public net benefits of change are positive.*

2. *Do not use positive incentives if landholders would adopt land-use changes without those incentives.*

3. *Do not use positive incentives if private net costs outweigh public net benefits.*

The following two rules are based on the use of extension to improve decision making, rather than to improve skills. They relate to the use of extension as the main policy tool, rather than as a support to other policy mechanisms.

4. *Do not use extension unless the change being advocated would generate positive private net benefits. In other words, the practice should be sufficiently attractive to landholders for it to be 'adoptable' once the extension program ceases.*

5. *Do not use extension where a change would generate negative net public benefits*

The remaining rules are as follows:

6. *If private net benefits outweigh public net costs, the land-use changes should be accepted if they occur, implying no action. Alternatively, if it is not known whether private net benefits are sufficient to outweigh public net costs, a relatively flexible negative incentive instrument may be used to communicate the public net costs to land managers (e.g. a pollution tax), leaving the ultimate decision to the land managers. Inflexible negative incentives, such as command and control, should not be used in this case.*

7. *If public net costs outweigh private net benefits, use negative incentives to discourage uptake of the land use.*

8. *If public net benefits and private net benefits from a set of land-use changes are both negative, and landholders accurately perceive this, then no action is necessary. Adverse practices are unlikely to be adopted. If there is concern that landholders have misperceptions about the relevant land uses, adoption of environmentally adverse practices could be discouraged by extension, or more strongly by negative incentives.*

The simple framework in Figure 1 is useful as a communication tool, particularly for communicating the underlying economic principles to non-economists.

4. Refined framework for static technologies

Pannell (2008) describes a number of additional complexities that influence the choice of policy mechanism:

- There are learning costs that inhibit land-users from adopting new technologies;
- There are time lags between the availability of an practice and its adoption by landholders;
- The time lag to adoption for a specific technology is likely to be inversely related to the private net benefits of adoption;
- Extension is likely to reduce but not eliminate the lag to adoption;
- There are transaction costs involved in any intervention.

Capturing the influences of these factors in the framework requires specific assumptions about functional forms and parameter values. For the purposes of illustration, the following assumptions are made (largely based on Pannell, 2008).

- Learning costs are the same for every project: $10/ha/year in annualised form.
- The lag to adoption (λ) is ∞ for private net benefit (π_i) ≤ 0, and decreases at a decreasing rate as π_i rises above zero. The specific form for this relationship is an empirical question. For illustration, assume that $\lambda = k/(\pi - C_L)$; $\pi_i - C_L > 0$, where k is a constant, assumed to equal 50.
- Extension reduces the time lag to adoption by two years, based on Marsh et al. (2004).
- The real discount rate is 5%.
- Transaction costs are $2.50/ha/year for positive incentives (excluding transfers such as subsidy payments), negative incentives, and extension.

All numerical values in subsequent figures are expressed as annuities. Calculations are available at http://cyllene.uwa.edu.au/~dpannell/archive/pub-priv2.xls.

With these assumptions, the revised framework is shown in Figure 2. The boundaries shown in Figure 2 map those projects where the BCR of intervention = 1, and any project inside the areas labeled *Positive incentives*, *Negative incentives* or *Extension* would have a BCR > 1. The graph is generally similar to Figure 1. In broad terms, the differences are: (a) the boundary between *No action* and *Positive incentives* is moved to the right due to learning costs, (b) for projects with positive but low private net benefits, the recommended response is *Positive incentives* rather than *Extension*, as the time lag to adoption is high for these projects and it is assumed that positive incentives can eliminate that lag, (c) *Extension* is not recommended for some projects with positive but low public and private net benefits, because the transaction costs outweigh the resulting benefits, and (d) the left boundary between *Negative incentives* and *No action* is moved to the right because, with learning costs considered, landholders would not adopt changes with low private net benefits.

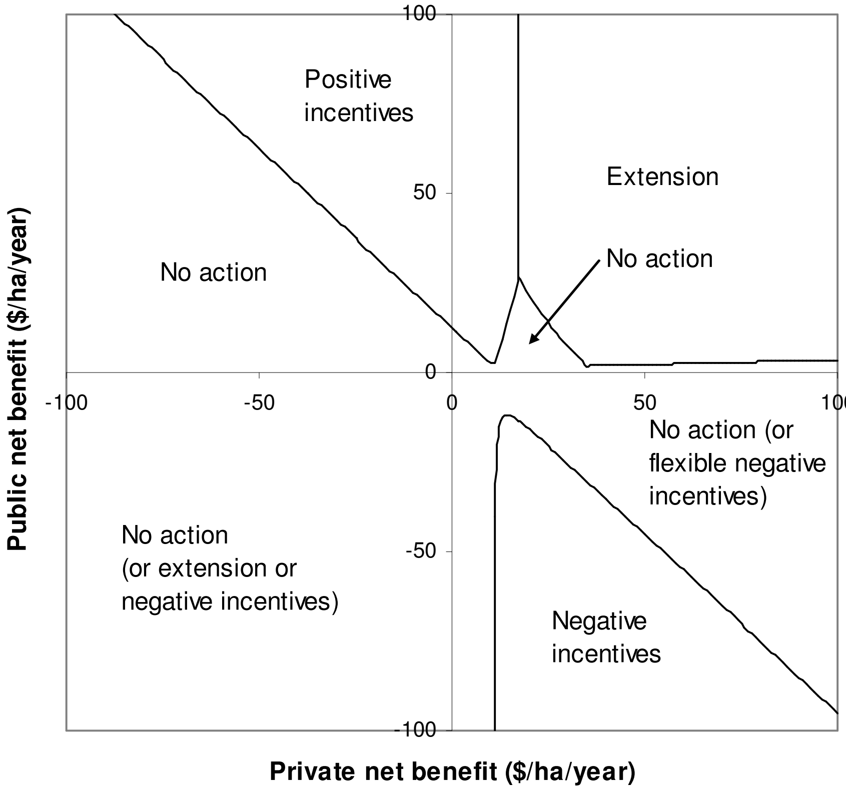

Figure 2. Refined framework for BCR ≥ 1, allowing for lags to adoption, learning costs and transaction costs.

Figure 3 shows results for the same set of assumptions, but for a BCR of at least 2.0 in order to invest in incentives or extension. Use of a higher threshold BCR such as this could be relevant where there is a fixed program budget that is insufficient to fund all worthwhile projects. Broadly speaking, the higher-priority projects for incentives and extension are those where private net benefits are closer to zero, and/or public net benefits are further from zero.

Experience in presenting the framework to environmental managers and policy makers has revealed that the first of those results (that BCRs are higher for projects with private net benefits close to zero) is not obvious to some. The reasons for the result are as follows. In the north-west quadrant, for a given level of public net benefits, the BCR of positive incentives increases as we move towards the vertical axis, because such a movement implies a reduction in the opportunity cost of land-use change. In the north-east quadrant, starting with a high private net benefit, the BCR of extension is low because the lag to adoption is low even without extension. As the private net benefit decreases, up to a point, extension makes a bigger difference to the adoption lag. (Beyond a certain point, the lag to adoption becomes longer than the lag reduction due to extension, and the BCR from further reductions in private net benefits starts to fall.)

In the south-east quadrant, the opportunity cost of preventing land-use change decreases as we move towards the vertical axis. If public benefits are unchanged, the BCR increases.

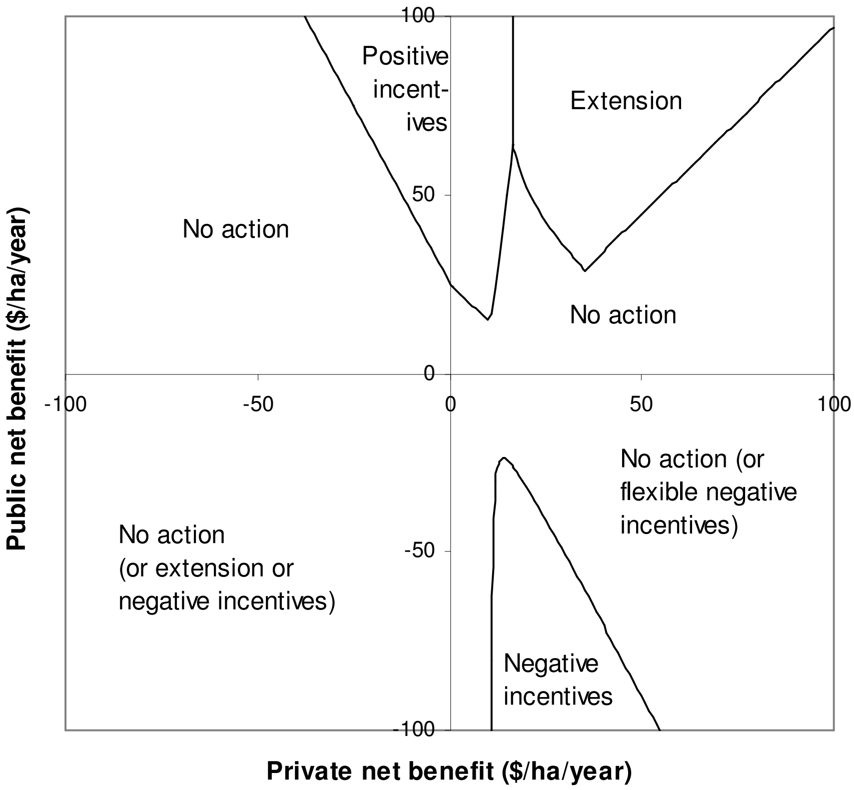

Figure 3. Refined framework for BCR ≥ 2, allowing for lags to adoption, learning costs and transaction costs.

5. Technology change

In this context, technology change refers to any intervention that improves the net benefits of the available land-management options. This could mean development of improved land management options, such as through strategic R&D or participatory R&D with landholders. Alternatively, it could be achieved by training of landholders to improve their skills at implementing an existing land use.

Technology change through R&D generates new potential projects that are to the right of (more attractive to landholders) or above (more attractive to the public) existing options. Technology change through training may move an existing set of land-use changes to the right and/or upwards.

In the following discussion it is important to make a clear distinction between the benefits of a technology-change intervention, and the benefits of land-use change. The two axes plot the public and private net benefits of land-use changes, while overlaid on this are iso-BCR lines representing the net benefits of the policy intervention to undertake technology change. The location of iso-BCR lines is based on the net benefits of land-use change for technologies that exist prior to the investment in technology change. It is the changes in these benefits of land-use change that provide the benefits from technology change.

The merit of technology change through R&D depends on a range of factors (e.g. Alston et al., 1995) including: the predicted improvement in public and/or private benefits of the new technology relative to the best previous technology; the likelihood of R&D delivering those predicted benefits; the time lag until delivery of improved technologies; the discount rate; and the cost of conducting the R&D. Most of the same categories of issues are relevant to valuation of a training intervention. We would expect that the lag time between intervention and benefits would be shorter for training than for R&D. On the other hand, the potential for improvements in private net benefits may be higher for R&D.

Suppose that technology change results in a new technology that provides an additional $50/ha/year of private net benefit compared to the best previous technology. Assume that other variables are such that, if the new technology is adopted promptly, the BCR of investing in technology change is 4.0 (e.g. public benefits unchanged, discount rate 0.05; research lag 10 years, cost of research $4.60/ha/year annualized, probability of research success 0.6). Also assume that, after the 10-year research lag, the new technology would replace another similar already-adopted technology and would require no learning cost. Figure 4 shows the map of BCRs for such a technology change intervention, as explained below and in Figure 5. (Only the northern half of the full graph is shown, as this is the area where technology development is most relevant.)

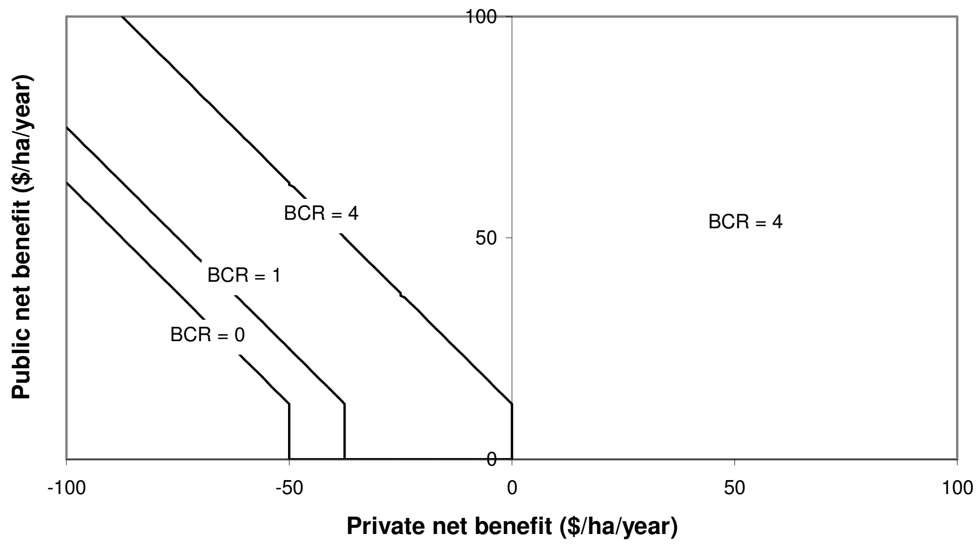

Figure 4. BCRs for technology change projects.

The interpretation of the graph is as follows. Suppose there is a land-use-change project based on current technologies that is located on the BCR = 4 line (e.g. a project for which the private net benefits are -$30/ha/year and the public net benefits are $42.5/ha/year. Then, if investment in technology change moves the project $50 to the right, the BCR of the investment in technology change will be 4.0.

The BCR = 4 line for technology change corresponds to the BCR = 1 line for positive incentives in Figure 2. All projects to the right of that line would have the calculated BCR of 4, because they all would involve replacing an already-adopted technology – the adoption of an existing technology would have been prompted by positive incentives or extension, or would have occurred spontaneously (after the assumed lag) due to the private net benefits of adoption. The BCR = 0 line is to the left of the BCR = 4 line by $50 (or more generally by the increase in private net benefit due to the technology change).

Depending on the current levels of public and private net benefits from land-use change (prior to technology change), the benefits of a technology change that increases private net benefits consist of a mix of cost savings (reducing the opportunity cost for those cases where current technology has a negative private net benefit) and increased benefits (private in this case, but potentially public).

To illustrate, see Figure 5. Consider the case where the initial technology is at point A (private net benefits = 25, public net benefits = 50). Technology change creates a new potential project with $50/ha/year higher private net benefits, and the benefits are equal to that $50. If we start with technology B (-20, 75), a similar improvement in the technology results in a cost saving of $20 (i.e., removal of a subsidy of $20/ha/year, or avoidance of a $20 opportunity cost) plus a private benefit of $30, again totaling $50. For technology C (-35, 30), there is no benefit from moving to the right until the technology reaches the BCR = 4 line, after which there are $20 of savings and $15 of positive private benefits, totaling $35. For technology D (-60, 60), there is a benefit of $40/ha/year, consisting of reduced opportunity cost. For technology E (-70, 14), improving private net benefits by $50/ha/year has no benefits, as the improved technology would still not be worth adopting, and would not be attractive enough for it to be worth introducing positive incentives.

Any project where the current technology is to the left of the BCR = 0 line (like E) would similarly have no net benefits as a policy intervention. BCRs change linearly between the BCR = 0 and BCR = 4 lines.

The locations of the five projects illustrated in Figure 5 interact with whether the environmental manager uses polluter-pays or beneficiary-pays mechanisms to influence the attractiveness of each project to the environmental manager (Table 2). If a beneficiary-pays mechanism is used, cases B, C and D generate benefits to the environmental manager. The nature of the benefits is different in each of these three cases. If the environmental manager is already making incentive payments to landholders (case B), technology change allows a reduction in those payments. In case C, the change in private net benefits is sufficient to take a project from being unattractive to all stakeholders, to being sufficiently attractive to private landholders for incentive payments to be unnecessary. In case D, the results of technology change would be a project that warrants incentive payments from the environmental manager to the land manager, whereas no such payments (and no environmental benefits) would occur otherwise.

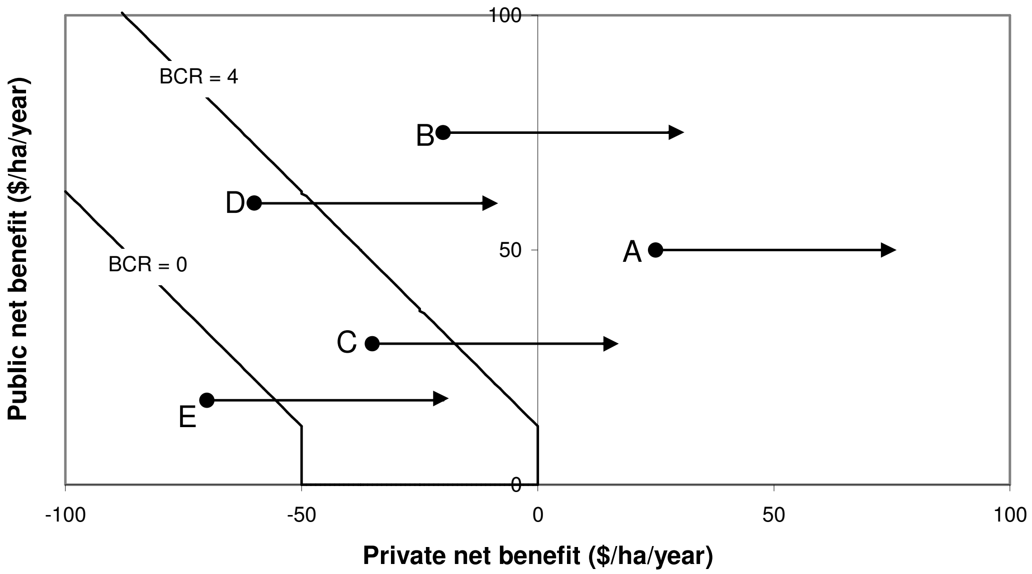

Figure 5. Five illustrative technology-change projects.

If a polluter-pays mechanism is used, all benefits in case B would flow to the private landholders. Cases C and D are similar to the beneficiaries-pays example, except that in case D, the private landholder is a net loser as a result of the technology change. He or she would have to bear an opportunity cost that otherwise would not be justified.

Of course, the maximum BCR from a particular technology change is not necessarily 4.0. Table 3 shows how the potential BCR from technology change would vary depending on the improvement in private net benefits, the time lag before benefits, and the annualized cost of the project (assuming a discount rate of 0.05, probability of success of 0.6, and no change in public benefits). For most of these projects, BCRs are high relative to other policy mechanisms illustrated in Figures 2 or 3. For these alternative projects, the position of the maximum BCR line would be unchanged (Figures 4 and 5) but its BCR would be altered from 4 to the values shown in Table 3. As the improvement in private net benefit varies, the effect would be to move the BCR = 0 line left or right so that its horizontal distance from the maximum BCR line is equal to the improvement in private net benefit. If the BCR from technology change is less than 1.0, (e.g. there is an example of 0.9 in Table 3) then technology change would not be recommended for any combination of public and private net benefits.

Table 2. Who benefits from the technology change?

Technology change project (from Figure 3)	Polluter-pays mechanism used for positive incentives	Beneficiary-pays mechanism used for positive incentives
A	Private landholder only	Private landholder only
B	Private landholder only	Environmental manager (reduction in incentive payments) and private landholder
C	Environmental manager (greater adoption of environmentally beneficial practices motivated by private benefits) and private landholder	Environmental manager (greater adoption of environmentally beneficial practices motivated by private benefits) and private landholder
D	Environmental manager (environmental benefits through enforcement of a polluter-pays instrument). Private landholder loses the remaining opportunity cost after technology change.	Environmental manager only (potential to support land-use change through incentive payments, which were not viable previously)
E	Neither	Neither

Table 3. Benefit cost ratios for different technology-change projects.

		Cost of project ($/ha/year)		
Improvement in private net benefits ($/ha/year)	Time lag (years)	2.5	5	10
25	2.5	5.3	2.7	1.3
50	2.5	10.6	5.3	2.7
100	2.5	21.2	10.6	5.3
25	5	4.7	2.4	1.2
50	5	9.4	4.7	2.4
100	5	18.8	9.4	4.7
25	10	3.7	1.8	0.9
50	10	7.4	3.7	1.8
100	10	14.7	7.4	3.7

The above graphs are for technology changes that only improve private net benefits (e.g. a new land use that would provides the same public net benefits but higher private net benefits than an existing land-use option). Improvements in public net benefits may also be possible. This would result in iso-BCR lines for technology development that are displaced vertically (for technology-change projects that only improve public net benefits) or diagonally (for technology-change projects that improve both public and private net benefits) relative to the maximum BCR line.

Figure 6 shows how the results for technology change can be added to Figure 2 (for BCR ≥ 1). The dashed line in the north-west quadrant indicates that the location of that boundary is dependent on the extent of improvement in private net benefits. (The extent of the vertical section of this line would be different depending on the extent of change in public net benefits from the technology change.)

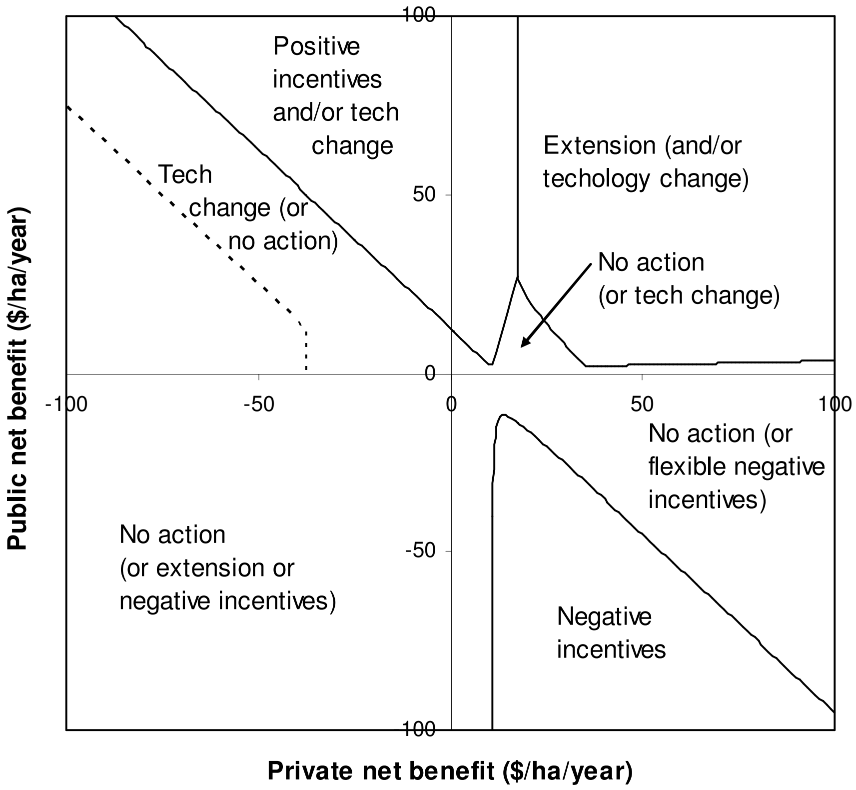

Figure 6. Refined framework for BCR ≥ 1, including technology change

Compared with Pannell (2008), who suggested technology change for any projects to the left of the BCR = 1 line in Figure 2, this more detailed assessment is different in three ways: (a) recognition that if the initial private net benefit is too negative, it is not possible for technology change to yield benefits, particularly if public net benefits are low, (b) recognition that the BCR of technology change is highly variable and needs to exceed 1.0, and (c) recognition that the highest potential benefits from technology change are actually to the right of the BCR = 1 line in Figure 2.

The different emphases given to technology change in the labels of Figure 6 reflect the distribution of benefits revealed in Table 2. In the region marked "Tech change (or no action)", technology change is the only option for generating positive net environmental benefits. In the region marked "Positive incentives and/or tech change", the two options are both potentially good candidates for an environmental manager. In the north-east quadrant, all benefits are captured by the landholder, so technology change that only improves private net benefits, while socially beneficial, may not be so attractive to an environmental manager. On the other hand, technology change that enhances the environmental benefits from land-use change would be more attractive to them.

6. Conclusion

The broad implications identified by Pannell (2008) remain relevant in the modified framework. It remains true that particular mechanisms should be used as follows:

- positive incentives where public net benefits are highly positive and private net benefits are slightly negative;

- negative incentives where public net benefits are highly negative and private net benefits are slightly positive;

- extension where public net benefits are highly positive and private net benefits are slightly positive;

- no action where private net benefits outweigh public net costs, where public and private net benefits are both negative, where private net benefits are sufficiently positive to prompt rapid adoption of environmentally beneficial activities, or where private net costs outweigh public net benefits (provided that technology change is not sufficiently attractive).

Further, the following general conclusions remain:

- If they are to generate substantial net benefits, positive incentives, negative incentives and extension need to be carefully applied to projects that fall in the indicated areas.

- The selection of cost-effective environmental projects depends just as much on the level of private net benefits as on public net benefits.

- Projects are more likely to generate high payoffs to investment in positive incentives, negative incentives or extension if the private net benefits are reasonably close to zero.

In addition, the following new conclusions emerge from this study:

- The benefits of technology change are greatest for projects where private benefits are at least high enough for policy intervention to be worthwhile to encourage land-use change even without technology change. This applies to the right of the BCR = 1 line for positive incentives, and within that set, technology change projects are likely to be of most value to an environmental manager within the positive incentives area, rather than in the extension or no action areas in the upper right quadrant.

- There is a set of projects for which technology change is the only viable alternative to no action, highlighting the importance of technology change in these cases. These projects are located to the left of the BCR = 1 line for positive incentives but near enough to that line for technology change to create beneficial new project options.

In the course of the analysis, technology change has been found to be of benefit in a variety of ways, depending on the nature of the change and the existing levels of public and private benefits of land-use change (i.e. before technology change). Benefits may accrue in the following ways:

- Increasing the adoption of environmentally beneficial land uses through enhancing the private net benefits of adoption;
- Reducing the opportunity costs borne by private landholders subject to polluter-pays instruments;
- Reducing the financial costs borne by environmental managers who are applying beneficiary-pays mechanisms;
- Generating new opportunities for land-use change projects that were previously too costly or not beneficial enough to be worth pursuing;
- Increasing private net benefits from land-use changes that would have happened even without the technology change; and
- Increasing the environmental benefits of land-use changes that would have happened even without intervention.

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