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ECONOMIC ANALYSIS OF ENVIRONMENTAL AND NATURAL RESOURCE PROBLEMS IN AGRICULTURE

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TABLE OF CONTENTS

ABSTRACT iii

1. INTRODUCTION 1

2. OPTIMAL USE OF ENVIRONMENTAL AND NATURAL RESOURCES . . 4
   - 2.1 Notions of Optimality 4
   - 2.2 Causes of Sub-Optimal Resource Use 6
   - 2.3 Effect of Market Failures 8
   - 2.4 Effect of Policy Distortions 12
   - 2.5 Effect of Simultaneous Market Failures and Policy Distortions . . . 14
   - 2.6 Optimal Resource Policy 17

3. ECONOMIC ANALYSIS OF ENVIRONMENTAL AND NATURAL RESOURCE PROBLEMS 20
   - 3.1 Cost-Benefit Analysis 20
   - 3.2 The Policy Analysis Matrix 23
   - 3.3 Integrating Cost-Benefit Analysis and Policy Analysis 25

4. CONCLUSIONS 29

REFERENCES

LIST OF FIGURES

1. Linkages in Farmer Decision-Making 8
2. Privately and Socially Optimal Activity Levels in the Presence of Market Failures 9
3. Choice of Technique in the Presence of Market Failures 11
4. Effect of Subsidies on Input and Output Prices on Activity Levels 13
5. Optimal Activity Levels with Simultaneous Market Failures and Policy Distortions 15
6. Net Private and Social Benefits of Different Activity Levels with No, Partial, or Complete Removal of Market Failures and Policy Distortions when Policies Encourage the Activity 17
7. Net Private and Social Benefits of Different Activity Levels with No, Partial, or Complete Removal of Market Failures and Policy Distortions when Policies Discourage the Activity 17
8. Source of Budget Data for Cost-Benefit Analysis 21
9. Policy Analysis Matrix and Source of Budget Data for its Construction 24
10. Combined PAM and CBA Matrix for the Analysis of Environmental and Natural Resource Problems Involving Market Failures and Policy Distortions . . . 26

Abstract

Analysis of environmental and natural resource problems is often complicated by the simultaneous presence of both resource-related market failures and policy-induced distortions. In such a context, efforts to remove policy distortions may not be desirable if significant market failures remain, or conversely addressing the market failures may not be worthwhile if the economic environment remains highly-distorted. Despite the simultaneous presence of both types of problem, however, most analysis has generally focused on one or the other exclusively. Cost-Benefit Analysis (CBA) and the Policy Analysis Matrix (PAM) are two tools that have been used in this way; their strengths and flexibility suggest, however, that they might be usefully combined into a single framework that allows a more integrated analysis of environmental and natural resource problems. This paper proposes an approach to doing so.

1. INTRODUCTION

Increasing concern has developed in recent years over environmental and natural resource problems resulting from agricultural production. Environmental degradation in agriculture takes a myriad of forms, ranging from the depletion of topsoil to the contamination of waterways by runoff polluted with agricultural chemicals to the exhaustion of aquifers. These problems have put in question the real benefits obtained from agricultural production and the sustainability of agriculture itself. With this increasing perception of environmental problems has come a search for its causes and for possible solutions.

Resources differ from other economic goods in being either non-producible (exhaustible resources) or subject to exogenously given production rules that economic agents can affect only indirectly (renewable resources).[1] Of all human activities, agriculture is the most closely related to the underlying resource base; and its spatial extent puts it in a position to affect the environment over a very wide area.

Traditionally, environmental degradation has been blamed on the failure of markets for environmental and natural resources to reflect accurately the value of these resources to society. Water pollution provides the classical example of this problem. Farmers have no incentive to limit their use of rivers as a waste dump for chemical residues since such use comes at no cost to them. Based on this understanding, efforts have been made to regulate resource use so as to reduce the impact of these market failures, either by imposing regulations that force particular kinds of behavior or by developing mechanisms that substitute for the missing markets.

Recent years, however, have also seen a growing awareness that many environmental problems are caused by inappropriate government policies. Indeed, some have argued that policy distortions are a primary culprit in many cases of sub-optimal resource use [Panayotou, 1993]. Sometimes, environmental problems are the direct effect of policies. For example, subsidies on the use of agricultural inputs tend to increase the use of chemicals, and hence the resulting pollution. Indeed, in some cases no agricultural production would be undertaken at all if it were not for subsidies to crop production. Sometimes the problems arise as side-effects of policies designed to address other goals.

Examples abound of the interaction between market failures and policy distortions in affecting the optimality of resource use.

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[1] The distinction between environmental and natural resources is that the former are generally *consumption* goods (clean air, scenic sites) while the latter are generally *production* goods (fossil fuels, soil). The word 'resources' will be used herein to refer to both environmental and natural resources, unless the context indicates otherwise.

- *Tellico Dam* - Although this case does not involve agriculture directly, it is probably the canonical case of policy distortions resulting in environmental degradation [Reisner, 1986]. The Tellico Dam was a Tennessee Valley Authority (TVA) plan to build Tellico Dam on the Little Tennessee River. Construction of the dam was challenged under the Endangered Species Act (in the first application of the Act) because it would lead to the extinction of the Snail Darter. Although supporters of the Dam attempted to portray the issue as one of conflict between economic and environmental objectives ("Should a worthless, unsightly, minute, unedible minnow outweigh a possible injustice to human beings?" asked Tennessee Congressman Howard Duncan) it was later shown that Tellico Dam was hopelessly uneconomic, even on a sunk cost basis.

- *Deforestation in the Amazon* - Subsidies to ranching, including tax holidays, investment credits, tax and duty exemptions, and subsidized credit, have led to extensive clearing of tropical rainforests in Brazil's Amazon region [Mahar, 1989; Repetto, 1988]. Land laws that made tenancy dependent upon clearing ('improving') the land led to further loss of forest. These forces have led to widespread conversion of virgin forest to pasture. This pasture, however, has proven to be very unprofitable—the soil degraded very rapidly once deprived of forest cover—and much of it has been abandoned. In addition to the loss of potentially viable extractive systems, there has been substantial loss of biodiversity and considerable insertion of greenhouse gases into the atmosphere.

Cases such as these have created a widespread belief that 'good economics is good environmental policy.' In such a context, it is legitimate to ask whether efforts to address the market failures are worthwhile if the economic environment remains highly-distorted. Conversely, however, it may also be asked whether removing policy distortions is desirable if significant market failures remain.

When environmental degradation results primarily from the effects of government policies, there is a potential for 'win-win' policies, in which removing distortions not only improves allocative efficiency in the economy but also reduces damage to the environment and to natural resource stocks. It is unrealistic, however, to expect to that there never will be trade-offs between allocative efficiency and environmental objectives.

This paper examines the interaction between policy and the environment, and seeks to examine the conditions under which 'good economics' is also good environmental policy and to evaluate the trade-off between economic and environmental objectives when this is not the case. These are not questions that can be answered in the abstract; their answers will be case-specific, depending on the particular conditions faced. Accordingly, the focus of this paper is to develop tools that allow the costs and benefits of activities that have an impact on the environment and the extent to which these activities are encouraged or discouraged by government policies to be examined in concrete empirical settings.

Many political economy questions arise in the course of such an exercise. Efforts to improve the use of environmental and natural resources often run afoul of entrenched forces that have a vested interest in the current pattern of resource use. Indeed, many of the policies that adversely affect the environment were initially enacted to satisfy such groups. Opposition from such groups often prevents policies from being changed even after problems becomes evident. Tellico Dam provides a sobering reminder of this problem since, despite the adverse economic appraisal, it was ultimately built. The political interests that stood to benefit from the Dam's construction, no matter what its adverse effects on the environment and economic efficiency, proved strong enough to overcome Supreme Court injunctions and rulings from the cabinet-level Interagency Review Committee. There is a need, therefore, to understand the interests of different groups involved because their political power may prevent that policy from being adopted. Understanding the incentives faced by affected parties is particularly important in the context of agricultural production, because agricultural conditions tend to be very site-specific and because decisions regarding resource use in agriculture are ultimately made on a very decentralized basis by individual farmers. Unless enforcement mechanisms are very effective, attempts to change patterns of resource use in ways that adversely affect their interests are unlikely to prove successful.

The need to understand the effects of any proposed policy changes on the various affected groups is important even when the changes are enforcable and the affected groups are not in a position to pose a serious political threat to these changes since equity questions also often arise. Considerable deforestation in developing countries results from poor farmers being forced to clear forest in order to grow food necessary for their survival. Saving the rainforest may well be a worthwhile goal, but it will have an adverse effect on the already precarious well-being of such groups.

2. OPTIMAL USE OF ENVIRONMENTAL AND NATURAL RESOURCES

2.1 Notions of Optimality

Any discussion of sub-optimal use of environmental and natural resources requires a precise notion of what would constitute optimal use. This paper uses the standard economic criterion of Pareto optimality. A given allocation of resources is said to be Pareto optimal if nobody can be made better off without at least one person being made worse off. Conversely, changes are said to be Pareto-improving if some people are made better off while none are made worse off. Pareto-optimal resource allocations maximize the income of society; a Pareto-improving change, therefore, results in a greater total income than prior to the change.[2] By a suitable redistribution of these income gains, all members of society can be made at least as well off as they were before the change and some can be made better off.

As generally applied, however, this criterion is probably best expressed as one of *potential* Pareto optimality. That is, changes are said to be Pareto-improving if they lead to a more efficient allocation of resources—and hence to greater total income—in the economy, so that any individuals who are made worse off by the change could *potentially* be compensated by the winners. The distinction is important, because in practice redistribution of gains is seldom undertaken. This distinction is fundamental to many of the political economic and ethical questions raised by attempts to reach environmental objectives.

Where do environmental objectives fit in the Pareto framework? The first fundamental theorem of welfare economics states that competitive markets result in Pareto-optimal resource allocations. In many cases, however, markets for many resources and the services they provide either do not exist or work very poorly. If well-working markets for natural and environmental resources existed, the allocation generated by a competitive market would also provide for the optimal use of these resources. For example, if consumers value the existence of wildlife and scenic sites, they would express this through their demand functions and the equilibrium of the system would reflect this valuation.

Much of the literature on resource and environmental economics has focused on devising mechanisms that substitute for the missing or imperfectly working markets or on eliciting information about consumers' valuation of resources in cases where markets fail. In this light, the optimal use of natural and environmental resources is as much an economic efficiency objective as are the optimal use of man-made inputs and the optimal consumption of man-made goods.

In some cases, on the other hand, the use of natural and environmental resources has, implicitly or explicitly, been treated as an objective separate from any notion of economic

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[2] When used by economists, the term 'efficient' is synonymous to Pareto-optimal. A pattern of resource use that is not Pareto-optimal is inefficient.

efficiency. Just as equity, low unemployment, and food self-sufficiency are sometimes seen as worthy goals in their own right (either together with or, sometimes, above income maximization goals), environmental objectives can be seen as being different and separate from economic efficiency objectives. Society might prefer, for example, the most efficient sustainable pattern of resource use over the absolutely most efficient pattern of resource use.

Environmental objectives can, therefore, either be problems of efficient use of resources which would, in principle, be solved by well-functioning markets, or problems of reconciling efficiency and non-efficiency objectives. The distinction is an analytically important one. Inefficient use of resources resulting from poorly functioning markets results in Pareto-inferior allocations just as surely as poorly functioning markets for man-made commodities; total income will be lower than it might have been. Conversely, the imposition of non-efficiency environmental objectives creates the possibility of conflict between economic and environmental objectives. Imposing a constraint on a system can never lead to greater efficiency. If the constraint is non-binding—that is to say, if the environmental objective would have been met anyway—then income levels are unaffected. But if the constraint is binding, behavior will differ from that which would have maximized income and income will, by necessity, be lower. This is not to say that environmental objectives should not be pursued. But it must be recognized that pursuing them may lead to lower total income.

The role of the economist is slightly different in each case. In cases involving market failure, the role of the economist is twofold: to discover what the optimal pattern of resource use would be, and to find ways of achieving that pattern. In cases involving non-efficiency environmental objectives, on the other hand, the goal is determined exogenously and the role of the economist is limited to that of finding ways to achieve that goal at least cost or to measuring the cost of achieving it so that policy-makers can determine whether the goal is worth pursuing. Whether a non-efficiency environmental goal is worth pursuing is not a question that an economist is equipped to anwer; an economist can only examine what the cost of pursuing it would be.

In actual empirical application, however, the distinction between problems resulting from market failure and problems resulting from non-economic objectives often becomes blurred. Establishing the optimal pattern of resource use in cases of market failure is a very complex task. By the very nature of the problem, data concerning it will generally not be observed. In the face of this difficulty, it has become common to impose a particular standard which is thought to be closer to the optimal pattern of resource use than current practice, and to find the least-cost way to meet this standard. The steps involved in doing this are no different from those required to examine the impact of non-efficiency environmental objectives; only the interpretation differs. When a non-efficiency environmental objective is being pursued, the cost of doing so, in terms of reduced total income, is a cost to society. When a standard is imposed in an effort to mitigate the effect of a market failure, the resulting 'cost' is only an apparent one. Society is better off because the

inefficiency in resource use resulting from the market failure has been reduced. A proper measurement of total income would reveal that total income increases after the change.[3]

The Pareto optimality criterion, therefore, provides a concrete metric against which to measure the economic inefficiency arising from inappropriate resource use or the cost of achieving non-economic environmental objectives.

2.2 Causes of Sub-Optimal Resource Use

Ever since Adam Smith, economists have maintained that markets operate in such a way as to guide individual actions to produce the greatest possible social economic well-being. This notion is formalized in the first fundamental theorem of welfare economics, which states that competitive markets are Pareto efficient.

Many markets depart from the assumptions of the competitive market in important ways, and thus lose the presumption of efficiency. This is particularly true of markets for resources. Two kinds of departure from competitive market assumptions can be identified. The first is market failure. Markets simply do not exist for many resources or for the services that they provide. As we shall see, this failure can arise in several different ways. The second kind of departure from competitive market conditions results from government intervention in the economy. This intervention might be motivated by an effort to mitigate the effects of market failure or by a desire to pursue non-economic objectives.

An examination of the possible linkages between the actions of individual agents and the environment can help clarify the interaction of market failures and government distortions in affecting resource use. For concreteness, consider some farmers making their input and output choices. Their objective is generally to maximize profit from their farming operations. The kind of linkages that might be involved in the decisions of typical farmers are illustrated in Figure 1.

Decisions will, first of all, be affected by the farmers' technology and the agro-ecological conditions in which they are applying it. Under any given set of agro-ecological conditions, farmers with different technologies will make different production decisions. In semi-arid areas, for example, farmers with access to irrigation technology will make different production decisions than farmers without it. Conversely, similar technologies will work differently under different agro-ecological conditions, so farmers will adapt their production decisions accordingly. Production decisions will also be affected by the available stocks of natural resources. Farmers will not make the same production decisions if they have deep topsoil, for example, as they would if their soil has already been depleted by erosion. If the natural nutrients in their soil are low, they will tend to increase their use of chemical fertilizers. All these decisions will obviously be influenced by the price of each input and the

[3] This is the motivation for efforts to expand systems of national accounts to incorporate use of natural and environmental resources.

price of the output. The greater the price of any one input, the less the farmers' use of that input will tend to be. The greater the price of output the more farmers will attempt to produce and, therefore, the greater will be their use of all inputs, natural or man-made. Farmers may also face restrictions placed on their production decisions by government regulations. Farmers will take all these effects into account. It can be shown that they will tend to use all inputs up to the point where their marginal cost equals their marginal benefit.

The result of the farmers' production decisions will be, first of all, a certain quantity of output. Given the price and after substracting the costs of the inputs used, this determines the farmers' profits. But together with the good being produced, several 'bads' are often also produced. Residues from pesticide and fertilizer applications are washed off in run-off water or leached into groundwater, for example. In effect, farmers are using run-off water as a waste-disposal service. Unlike some of the other services farmers use in their production, however, they do not pay for this service. Its marginal costs to farmers is essentially zero no matter how much of it they might use. They will, therefore, tend to over-use it.

Agricultural production also frequently leads to depletion of natural resource stocks. Polluted effluents reduce the stock of clean water; erosion and other forms of soil degradation reduce the stock of soil services available to the farmer. Here it is important to distinguish two categories of resources: on-site resources and off-site resources. The main example of an on-site resource is the farm's soil. Reduction in the stock of this resource will have a direct effect on the future productivity of the farm. Farmers, therefore, will take this effect into account in making their production decisions. As was noted earlier, current resource stocks affect the farmers' production decisions; if these decisions in turn affect future stocks and hence future production decisions, farmers will take this into account. In this case, the marginal cost that farmers face is the reduction in future production possibilities resulting from the decline in resource stocks. The extent of this cost will, of course, depend on many factors. The more indispensable the resource is to production and the more difficult it is to substitute other inputs for the services it provides, the greater will be the marginal cost of depleting it. Because damage to the soil is often a long-term, cumulative process, it has often been argued that farmers will not take it into account. This is not completely correct. In many cases, problems such as poorly working land markets (that don't reflect soil quality) or tenure problems do lead farmers to place little weight on future degradation. Even in such cases, however, farmers will still take into account that portion of the damage that will be experienced in the period during which they expect to be using the land.

Off-site resources, on the other hand, are resources whose condition does not directly affect the farmers' future production possibilities. Effluents might reduce the supply of fresh water, but this problem will generally affect downstream users of the water, and not the farmers themselves. They will, therefore, tend to ignore this effect in making their production decisions. In other cases, the decision-makers might be affected by the pollution they emit, but still fail to take it into consideration because of public goods problems. For example, if chemicals leached from agricultural land contaminate groundwater, farmers who use groundwater will themselves be affected. But since their own contribution to the problem is

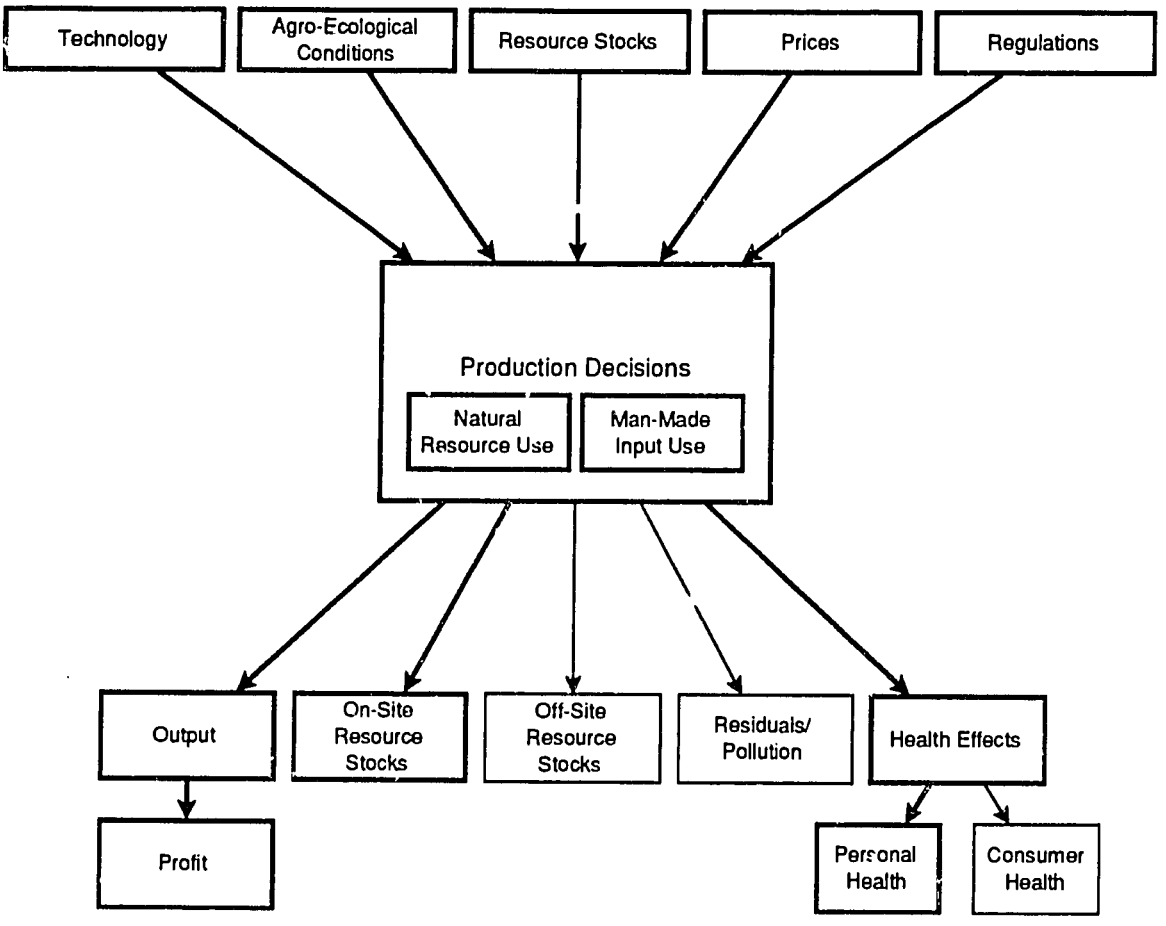

Figure 1. Linkages in Farmer Decision-Making

probably only a small part of the total problem, there is an incentive to attempt to free-ride—to let others bear the cost of reducing contamination to acceptable levels. Off-site resource degradation, therefore, will generally not be considered by farmers in making their production decisions, either because of externalities or because of public goods. It is important to distinguish between these two kinds of problems, since they are slightly different in nature, and are likely to require different solutions. The same considerations apply to possible adverse health effects of chemical use. Farmers will have an incentive to attempt to reduce adverse health effects on themselves (by wearing protective clothing, for example) but not to attempt to mitigate adverse health effects to others.

2.3 Effect of Market Failures

Figure 2 shows how the lack of markets for environmental damages leads to greater damage than would be optimal. The top panel shows the private revenue and costs experienced at different levels of the activity. The revenue curve (R) reflects output quantity multiplied by output price; given diminishing returns to production, this curve is concave.

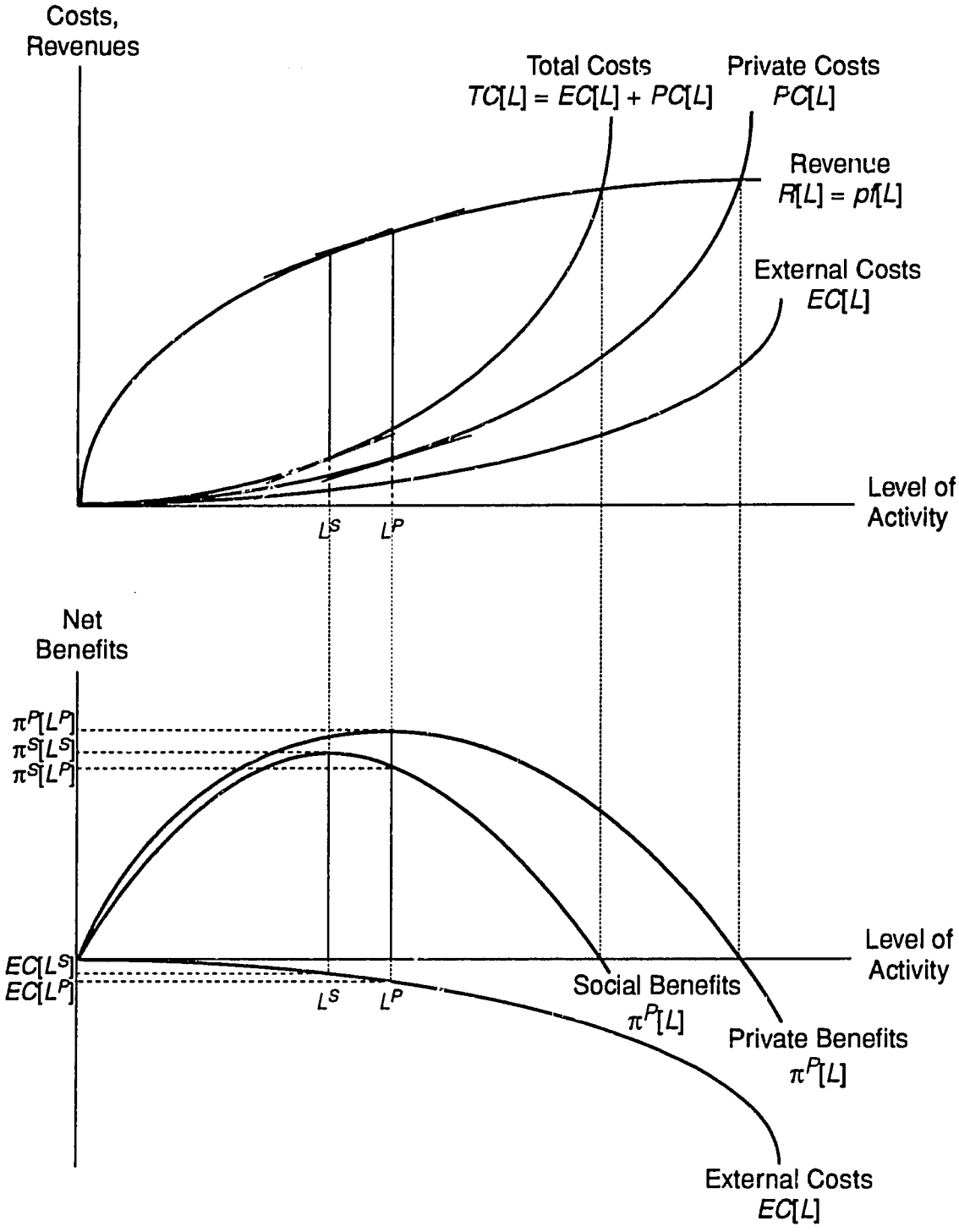

Figure 2. Privately and Socially Optimal Activity Levels in the Presence of Market Failures

The private costs curve (*PC*) reflects the costs of inputs—the value of all goods and services that enter into production that the farmers actually pay for. The lower panel shows the net private benefit curve (π^P), which is obtained by subtracting the private costs from the private revenues. The optimal level of production (L^P), based on these curves, is found where marginal revenues equal marginal cost or, equivalently, where private benefits reach a maximum . At this activity level, farmers make a private profit of $\pi^P[L^P]$. These returns, however, omit the external costs imposed on society by environmental degradation. For simplicity, suppose that external costs are directly related to the level of activity. The external costs curve (*EC*) shows what these costs might look like; it is reasonable to expect that they will rise as the level of the damaging activity increases. Although these costs are real, they are not borne by the farmers themselves, who will, therefore, ignore them. From society's perspective, the total costs of undertaking the activity are the sum of the private costs and the external costs. This total curve cost is also shown in the top panel of Figure 2. The bottom panel shows the corresponding net social benefits curve, π^S. If the total costs of the activity are taken into account, it is easy to see that the optimal activity level, L^S, is smaller than the optimal level from a private perspective. Unless these costs are taken into account, however, farmers will produce at level L^P, at which net social benefits equal $\pi^S[L^P]$, which are well below the maximum achievable social profits, $\pi^S[L^S]$.

In practice, the amount of environmental damage is likely to depend not only on the level of production but also on how production is undertaken. By using less of the polluting inputs, or investing in inputs or equipment that mitigate the damage, farmers might be able to produce the same amount of output with less environmental damage. For example, integrated pest management (IPM) techniques might be used to reduce pesticide applications. Such practices might reduce environmental damage, but they often also lead to higher costs. In some cases, they might also lead to lower revenues if lower pesticide applications result in a lower quantity and quality of output. Figure 3 illustrates this situation by comparing two hypothetical techniques, labelled 1 and 2, that produce the same output. Technique 1 is identical to the production system shown in Figure 1. Technique 2 is assumed to be less damaging, but to incur higher costs of production and have lower returns, at any level of production. As drawn, Figure 3 illustrates a situation in which technique 1 is preferable from the farmers' perspective, since it leads to higher net benefits. Technique 2 is preferable from a social perspective, however. Maximum social benefits are higher, because total costs per unit (once the lower the external environmental costs are taken into account) have fallen more than revenue per unit. Morover, social benefits are higher even if the external costs are not internalized (ie $\pi^{2S}[L^{2P}] > \pi^{1S}[L^{1P}]$).

Several points are worth stressing. First, although many economic activities have adverse environmental consequences, these are usually by-products of desirable consequences. It is often impractical to eliminate completely the adverse environmental effects of a given economic activity. Indeed, in some cases it is impossible; to the extent that any resource used in the production process is non-renewable, for example, *any* production will necessarily deplete the available stock of that resource. In Figure 2, even if all costs are taken into account, some amount of degradation does occur, resulting in a cost to society of $EC[L^S] > 0$.

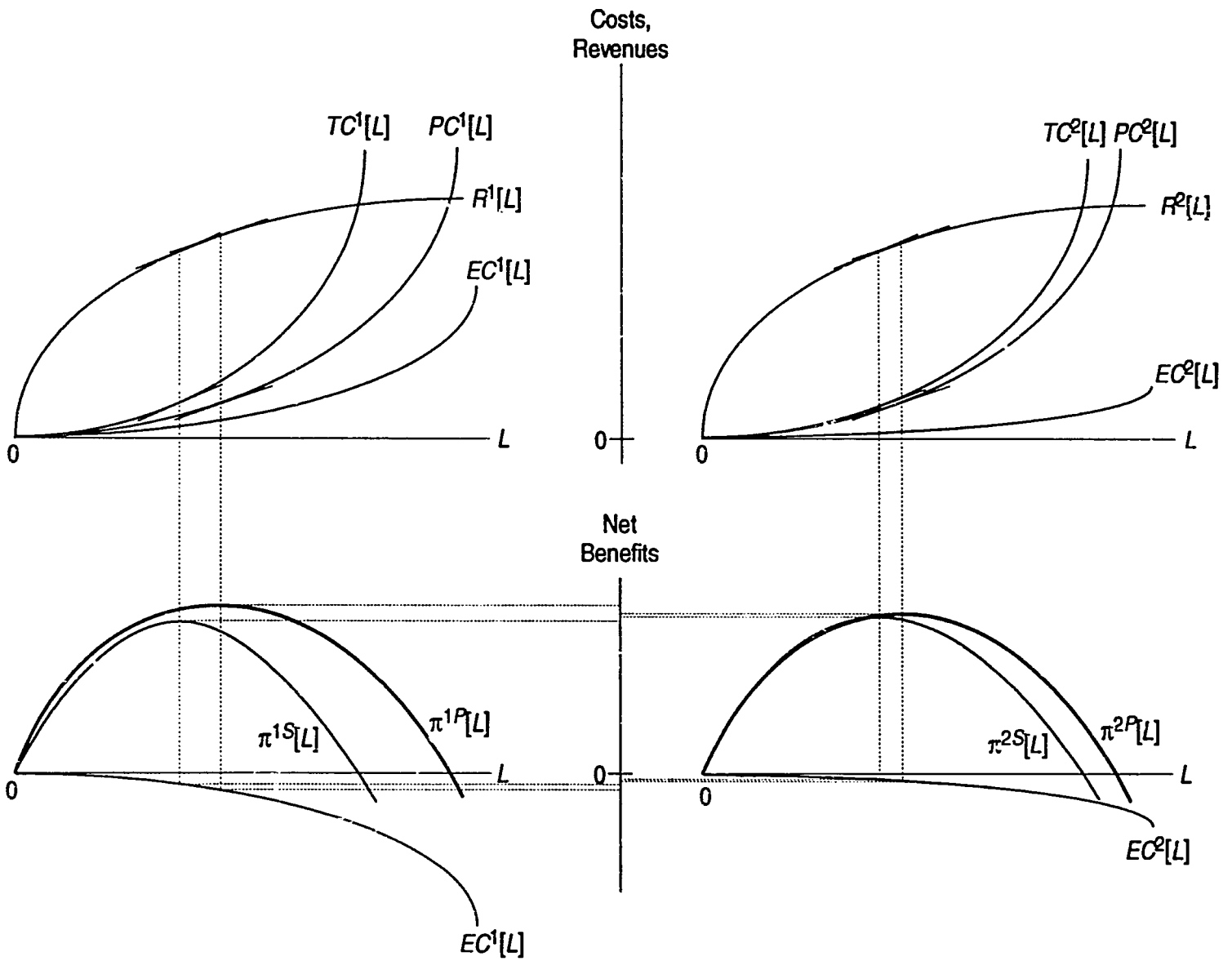

Figure 3. Choice of Technique in the Presence of Market Failures

Nevertheless, it remains true that the market failures often observed in resource markets lead to much greater environmental degradation than would be optimal: $EC[L^P] > EC[L^S]$. If all the environmental costs were taken into account, much lower levels of environmental degradation would result. However, even if all these costs are taken into account, there will often be some non-zero amount of degradation, as one of the prices that must be paid in order to obtain desirable goods.

It must also be stressed that this environmental damage need not result from either malice or ignorance. Rational, fully-informed economic agents will tend to ignore the adverse consequences of their actions if they do not bear these consequences. No amount of education will change this incentive. Moreover, even if the adverse consequences of production activities *are* taken into account, rational, fully-informed decision-makers will choose to bear some of these adverse consequences.

2.4 Effect of Policy Distortions

As was noted, farmers' production decisions are also affected by the prices they pay for inputs and the price they receive for their output. Other prices also play a role. In particular, the price of capital becomes critical as soon as production decisions take on an inter-temporal dimension, because of the linkages across periods caused by degradation of resource stocks. Many of the market failures that characterize the problem are, in fact, instances in which the price for resources is effectively zero, and thus does not reflect the true value of those resources to society. Even when prices are observed, however, they may not reflect the true social value of goods and services. In a perfect, competitive market, all prices will reflect the value to society of the goods and services they represent. Government interventions in markets, however, often distorts prices from what they otherwise had been. Taxes increase the effective price of goods on which they are levied to buyer of these goods; subsidies reduce the price of goods (here the farmer is the seller). Economic agents, therefore, will tend to use less of the goods that are taxed and more of the goods that are subsidized than they would otherwise have done. For example, if the output good is subsidized, the marginal benefit obtained at a given output level will be greater than it otherwise would have been, so farmers will tend to use more of every input. Thus, even if all resources had well-functioning markets, price distortions would lead to inappropriate levels of resource use.

Figure 4 illustrates the effect of price distortions on activity levels. For ease of exposition, no market failures are assumed to exist, so that total costs include the effect of environmental damage. The environmental cost component of total costs is shown separately in the lower panel, however. As an example, suppose that both the input price and the output price were subsidized, so that farmers received a higher price for their output and paid less for their inputs than they would have under competitive conditions. In this case, private revenues will be higher and private costs lower than social revenues and costs at all activity levels. As a result, the private net benefit curve will be higher than the social net benefit curve, and the activity will be engaged in at a higher level, thus resulting in higher than

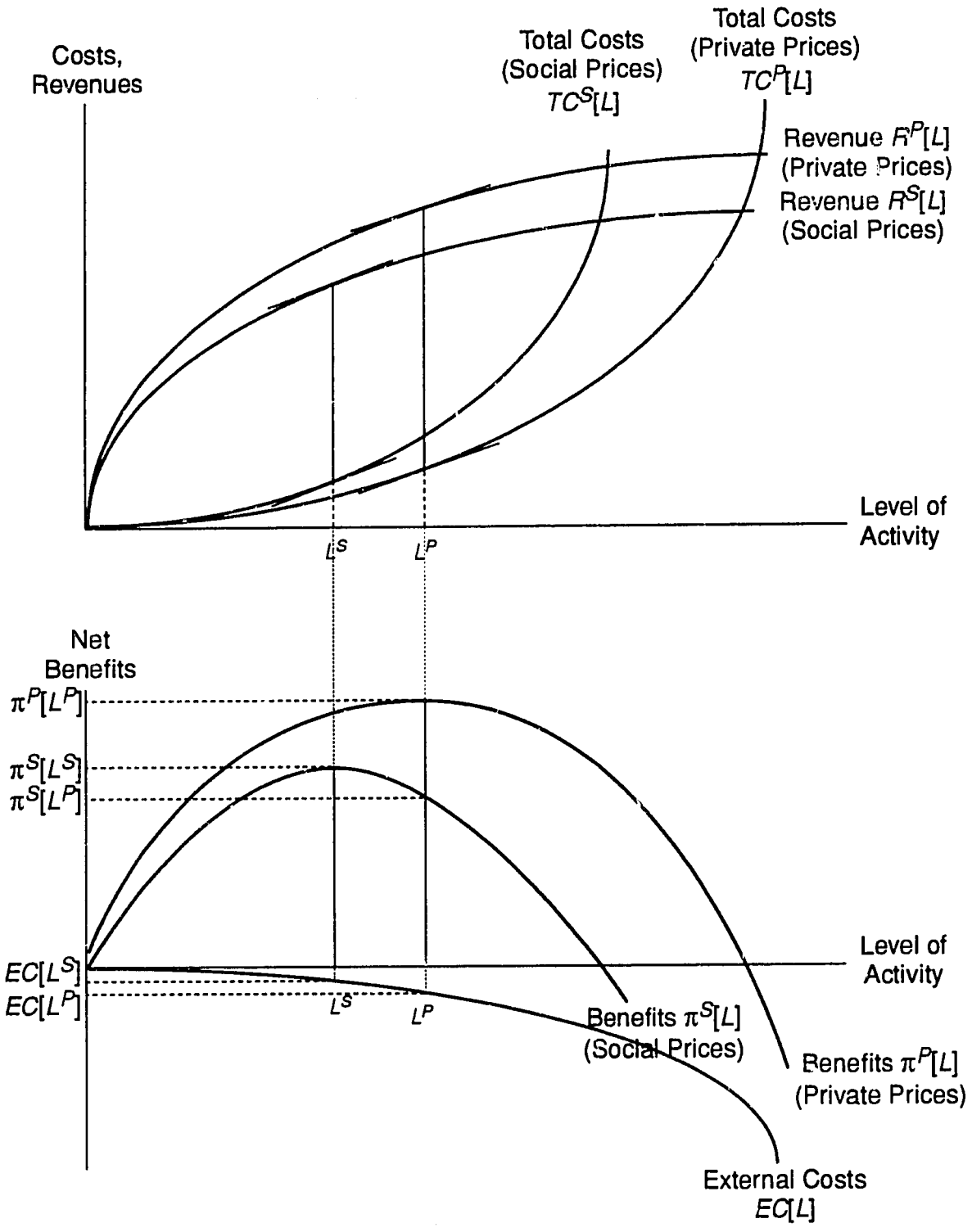

Figure 4. Effect of Subsidies on Input and Output Prices on Activity Levels

In the case of market failures, the effect on environmental degradation is unambiguous: greater amounts of degradation will occur than if markets worked properly. In the case of government-induced distortion, the net effect on degradation is indeterminate in general. The example shown in Figure 4 is one in which price distortions result in greater environmental degradation, but other combinations of policy can have different effects. If both input and output prices were taxed, for example, lower activity levels would be privately optimal, and lower levels of degradation would result. If output prices were taxed but input prices subsidized (a common policy mix in developing countries) their effects would tend to offset each other, so that the net effect on activity levels, and hence environmental degradation, would be indeterminate and would have to be established empirically.

A full analysis would need to examine the degree to which distortions affect input and output choices as well as the overall level of each activity. Inputs differ in the degree to which they are damaging to the environment. Subsidies to agricultural chemicals, for example, will lead to greater water pollution problems; subsidies to fertilizer might lead to greater soil degradation because they make substituting for the soil's natural fertility cheaper. Likewise, different products differ in the way in which their production processes affect the environment. Some crops require extensive chemical applications; others expose the soil to wind and water erosion.

2.5 Effect of Simultaneous Market Failures and Policy Distortions

In practice, problems due to market failures and problems due to policy distortions are often intertwined. Farmers make their production decisions in an environment in which there are both significant market failures and important price distortions. In some cases, one or the other problem may dominate. The effects of each will at times reinforce each other, and at times mitigate each other. The simultaneous presence of these different sources of market inefficiency means that analysts grappling with resource problems live in a second-best world. By the theorem of the second-best, there is no guarantee that removing one set of distortions will be Pareto-improving if other distortions remain.

Figure 5 illustrates a situation in which market failures and policy distortions are present simultaneously. In the left-hand panel, the effect of market failures alone is examined. Just as in the example in Figure 2, the presence of externalities means that higher-than-optimal levels of the activity are undertaken. In this panel, all resources are priced at observed prices; that is, at prices faced by private agents. The π^{PP} curve shows how private returns vary with the activity level when all resources are priced at private prices. The π^{SP} curve shows how returns vary with the activity level when externalities are internalized but all resources continue to be priced at private prices. These returns are "social" returns in the sense that they include the effects of externalities, but "private" in the sense that resources are not necessarily priced at their opportunity cost from society's perspective. This would be the situation if market failures could be eliminated but nothing was done to correct for policy distortions.

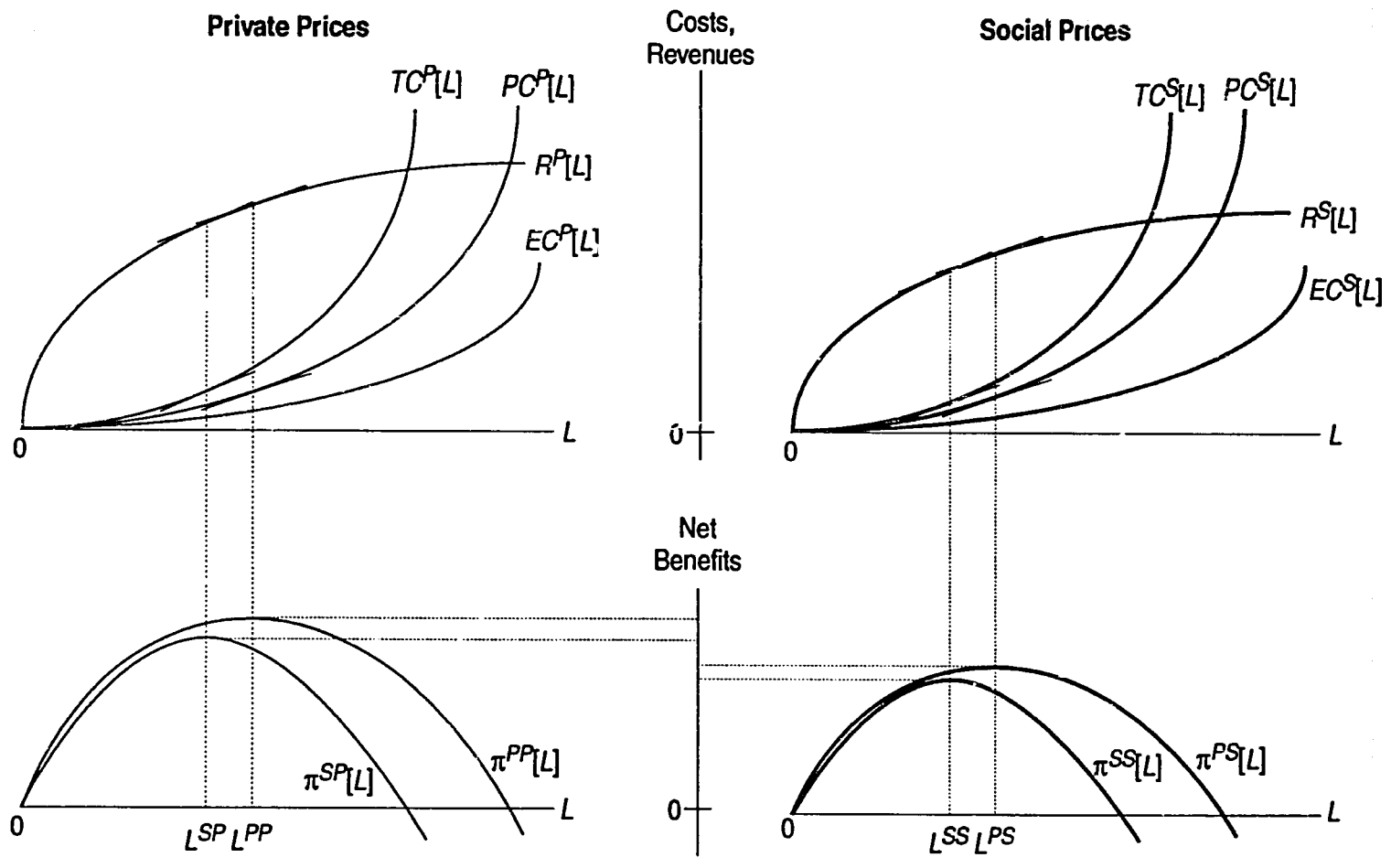

Figure 5. Optimal Activity Levels with Simultaneous Market Failures and Policy Distortions

The right-hand panel of Figure 5 shows the same comparison, but with all resources priced at social prices; that is, at their opportunity cost from society's perspective. The example shown in the figure is a case in which both the input price and the output price are subsidized, as in the example in Figure 3. The π^{PS} curve shows how returns vary with the activity level when all resources are priced at social prices but externalities are not internalized. These returns are "social" returns in the sense that resources are priced at their social opportunity cost, but "private" in the sense that they do not include the effects of externalities. The π^{SS} curve shows how social returns vary with the activity level when externalities are internalized and all resources are priced at their social opportunity cost. This last curve reflects the situation that would result if *both* market failures *and* policy distortions were removed.

Figure 6 summarizes the net benefits and the level of environmental damage that would be obtained under different situations. The highest activity levels, and hence the highest environmental costs, would be observed if neither market failures nor policy distortions were corrected for (L^{PP}). Private profits obtained by the agents undertaking this activity ($\pi^{PP}[L^{PP}]$) would be quite high. The actual social profits resulting from this level of activity, taking into account both the policy distortions and the external environmenal costs, is substantially lower ($\pi^{SS}[L^{PP}]$). If both market failures and policy distortions were corrected for, a lower level of the activity (L^{SS}) and a lower environmental cost would be chosen. The figure also shows the result of only removing one or the other source of suboptimal resource use. If only the price distortions were removed, for example, private agents would choose to produce at level L^{PS} and obtain private profits $\pi^{PS}[L^{PS}]$; social profits at this activity level would be $\pi^{SS}[L^{PS}]$. While this is lower than the maximum attainable level of social profits, it is an improvement over the initial situation. Similarly, removing the market failures without addressing the policy distortions would result in activity level L^{SP} and social profits $\pi^{SS}[L^{SP}]$, which would also represent an improvement. In fact, removing the market failures alone would result in a greater improvement than removing the policy distortions alone ($\pi^{SS}[L^{SP}] > \pi^{SS}[L^{PS}]$).

In the example in figures 5 and 6, addressing market failures or policy distortions individually would in each case lead to a Pareto-improvement. This conclusion, however, is solely a result of the particular type and magnitude of policy distortions assumed in the example. Since both externalities and the particular policy mix assumed act to increases the activity level relative to the social optimum, removing either would represent a Pareto-improvement in resource use. As discussed in the previous section, however, different policy mixes can have different effects on activity levels. Figure 7 provides an example of a case in which the net effect of the policy environment is to *discourage* an environmentally-damaging activity. This might be the case, for example, if output or input prices were highly taxed. In this case, removing the policy distortions alone would not lead to a Pareto-improvement, since more of the damaging activity would be enagaged in. If the policy distortions were removed without also removing the market failures, farmers would produce at level L^{PS}, at which social profits would be lower than under the current situation ($\pi^{SS}[L^{PS}] < \pi^{SS}[L^{PP}]$). By the same

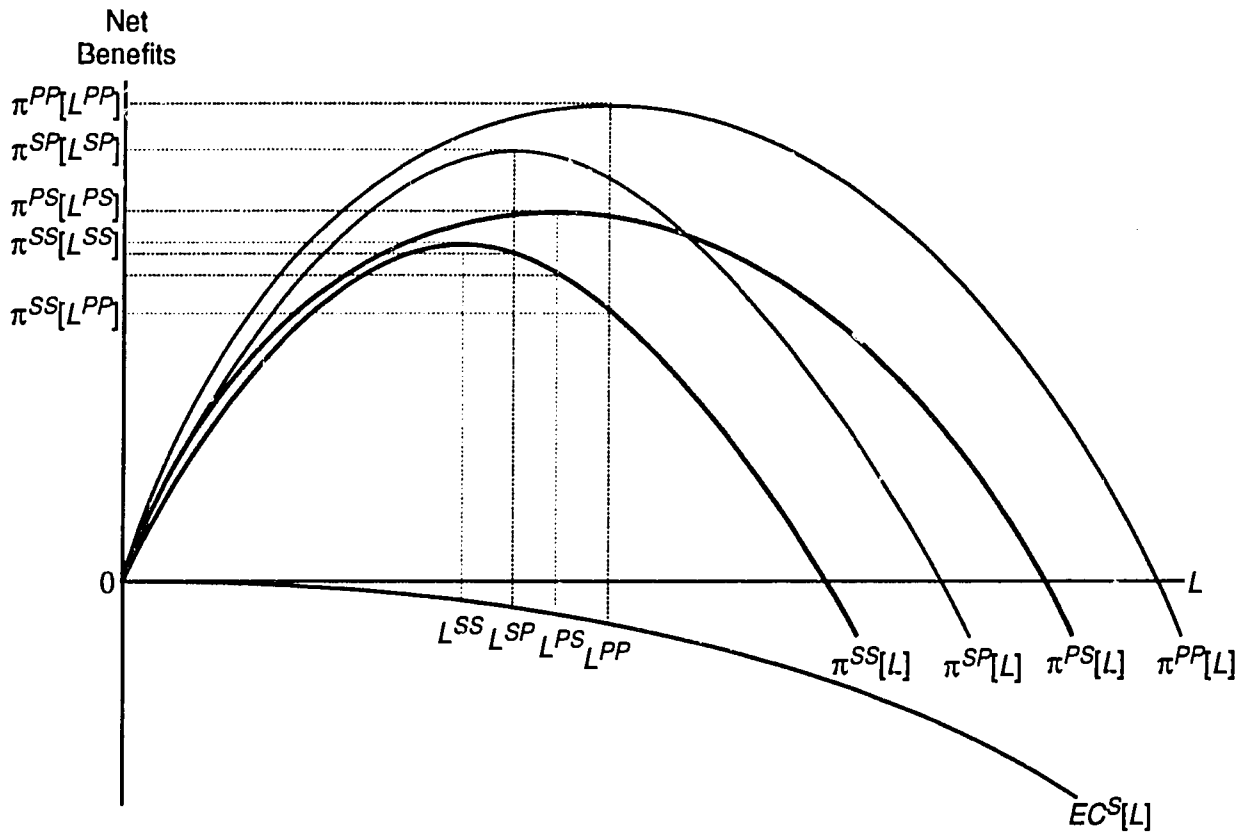

Figure 6. Net Private and Social Benefits of Different Activity Levels with No, Partial, or Complete Removal of Market Failures and Policy Distortions when Policies Encourage the Activity

token, removing the market failures alone would not necessarily lead to greater efficiency in the economy. As long as the policy distortions remain, too little of the activity would be engaged in, and social profits would remain below their possible maximum ($\pi^{SS}[L^{SP}] < \pi^{SS}[L^{SS}]$).

When both market failures and policy distortions are present, therefore, there is no guarantee that addressing either alone would lead to Pareto-improvements. Indeed, the result might actually be Pareto-worse. Tools are needed, therefore, to evaluate each situation empirically so that appropriate measures can be designed.

2.6 Optimal Resource Policy

As discussed earlier, optimal resource policy might imply one of two things. First, it might involve identifying the optimal pattern of use of natural and environmental resources, considered solely as economic goods. In the framework developed in the previous section this implies finding and achieving the optimal activity level, L^{SS}. Second, it might involve

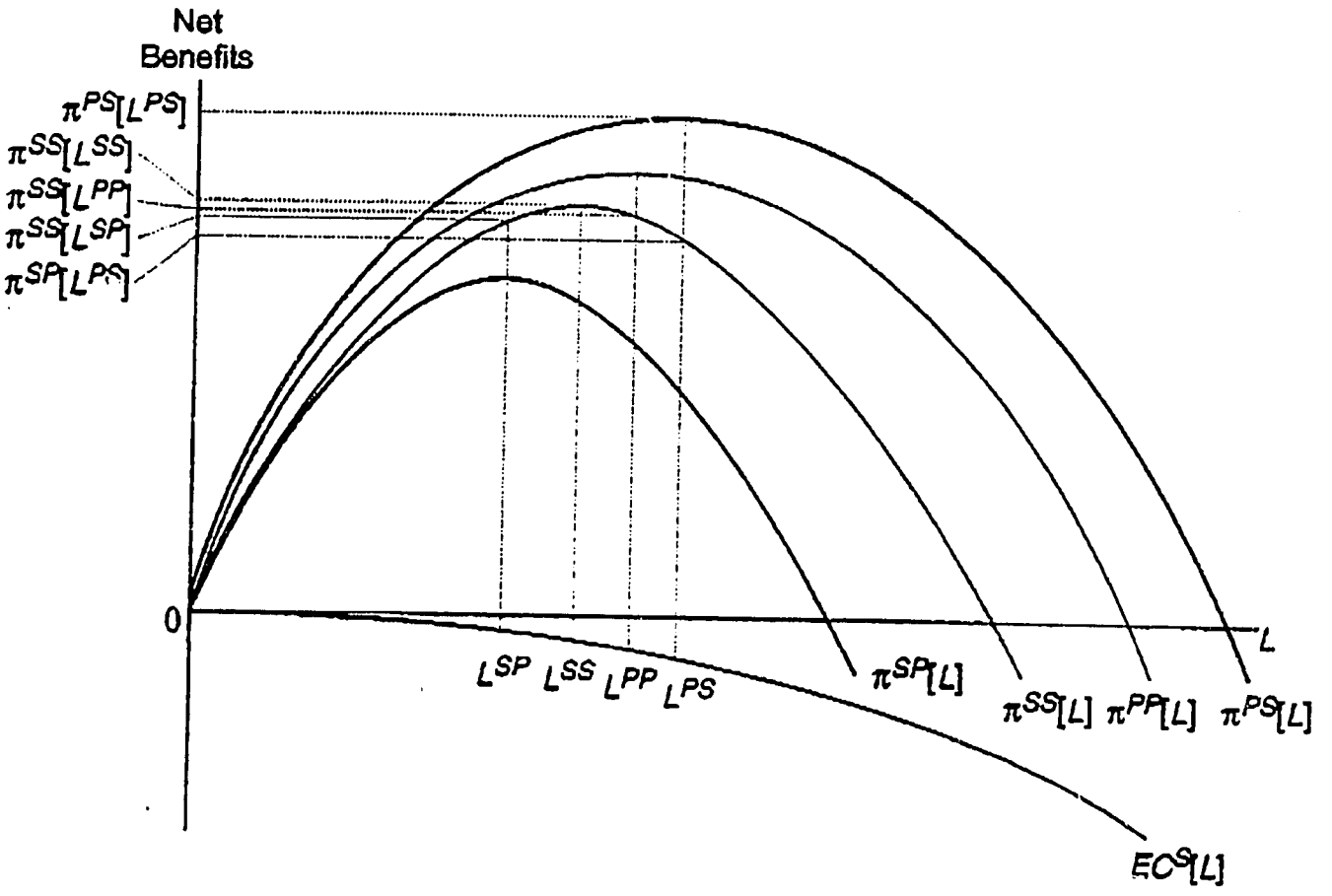

Figure 7. Net Private and Social Benefits of Different Activity Levels with No, Partial, or Complete Removal of Market Failures and Policy Distortions when Policies Discourage the Activity

finding the most cost-effective way of achieving an exogenously-decided goal. This objective can be represented as one of ensuring that environmental costs do not exceed some specified level, EC^{MAX}.

A considerable literature has developed that seeks to formulate mechanisms that substitute for the missing markets for natural and environmental resources. By adding a tax to the price of certain inputs, for example, the divergence between the private cost curve and the total cost curve can be reduced. The optimal such tax is that which would completely eliminate this divergence. Other proposed mechanisms seek to create markets where there are none through devices such as tradable pollution permits.

Given the difficulty of developing and enforcing optimal taxation schemes or of implementing alternative market schemes, many social planners have resorted to imposing standards which, while arbitrary, are thought to be preferable to the current situation. The reasoning behind such standards is that in the presence of market failures, the optimal level of activity, L^{SS}, is known to be lower than the current level, L^{PP}. Since finding L^{SS} is difficult or

impossible, it is preferable to impose a standard $L^{MAX} < L^{PP}$ and to require that it be met. Even when the objective is one of finding the most efficient pattern of resource use, therefore, the practical implementation is often very similar to that used to meet an exogenously-determined objective.

3. ECONOMIC ANALYSIS OF ENVIRONMENTAL AND NATURAL RESOURCE PROBLEMS

Although the problems to be addressed in resource issues are relatively well-understood qualitatively, empirical analysis has been severely constrained by formidable data requirements. In the problem outlined above, for example, determining optimal use rates for environmental and natural resources would require knowledge of the production relationships and of the way in which production affects environmental and natural resources, both of which are complex bio-physical relationships. Cost and benefit curves such as those depicted in the previous section would have to be estimated. Valuing environmental damage is a particularly difficult task because by the very nature of the problem environmental damage is often unobserved or observed in ways which make it difficult to relate it to its causes. Moreover, all of these relationships would also have to be estimated under unobserved social prices.

In this context, two tools provide some hope for detailed empirical analysis. The first is cost-benefit analysis (CBA), and the second is the Policy Analysis Matrix (PAM). CBA was originally developed as a tool to examine the economics of projects involving water resource development [McKean, 1958]. Although its application to resource issues was thereafter neglected for some time, it has once again come into widespread use for this purpose [Krutilla and Fisher, 1975; Hufschmidt *et al.*, 1983]. The PAM combines elements of CBA and principles of trade theory to give a detailed picture of the nature and source of policy effects on specific activities [Monke and Pearson, 1989].

3.1 Cost-Benefit Analysis

Cost-benefit analysis bases its approach on a comparison of returns under two alternative activities. Each activity is represented by a production budget which shows the costs and benefits, and hence the net return, of undertaking that activity in each time period. The question it asks is whether it is worth switching from one activity, characterized by a stream of net returns π^1_t, $t = 1,\ldots,T$, to a different activity, characterized by a stream of net returns π^2_t, $t = 1,\ldots,T$. This approach lends itself very well to empirical application, because data are often available in a suitable form.

Figure 8 shows where the budget data used in the cost-benefit analysis are obtained. Although the entire relationship between activity levels and cost or revenues cannot generally be observed, the actual costs and revenues of the current activity at its present activity level can generally be observed very easily.[4] A production budget for the activity at its current

[4] In a standard production theory framework, the farmers' objective is to maximize $pf[x] - c[x]$, where f is the production function (which combines the effects of the farmers' technology and of their agroecological environment), c is a cost function, and x is a vector of inputs. The solution to this problem is an optimal input level, x^*, and an optimal output level, $q^* = f[x^*]$. In practice, it is difficult to observe production and cost functions such

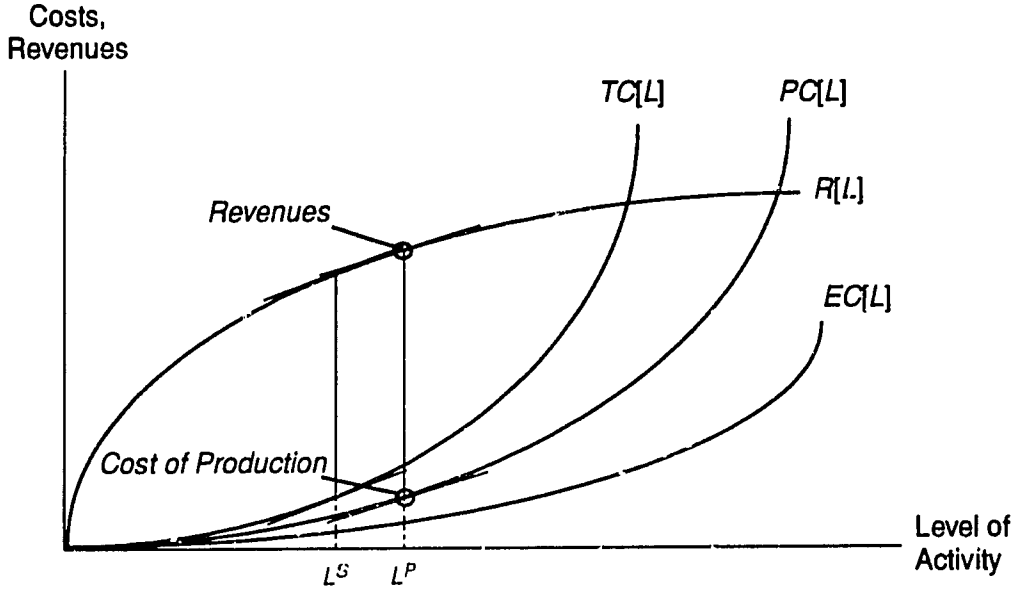

Figure 8. Source of Budget Data for Cost-Benefit Analysis

level can, therefore, be fairly readily constructed. A few inputs, such as family labor and other goods and non-services not obtained through markets, do pose problems, but there exist accepted ways of dealing with such problems [see, *inter alia*, Gittinger, 1982].

While the costs and revenues experienced under the current activity level can easily be observed, however, the same cannot be said of the external environmental costs. The costs and revenues of production at the socially-optimal activity level—assuming it were known—also cannot be observed. Often, however, the costs and returns of an alternative, less damaging technique can be observed. Consider technique 2 in Figure 3. Because it is less environmentally damaging than technique 1, its cost of production and revenue level diverge to a much smaller extent from the socially optimal levels.

Given that a second, less environmentally damaging, activity can be identified, the cost-benefit analysis can proceed by comparing its returns to that of the initial activity. If the streams of net returns under each activity are denoted by π^1_t and π^2_t, $t = 1,\ldots,T$, then the net present value (NPV) of the incremental benefits obtained by switching to technique 2 from technique 1 are given by

as $f[x]$ and $c[x]$, but easy to observe the resulting input and output choices, x^* and q^*, as well as the output price and the unit costs of individual inputs . Cost-benefit analysis uses these observed input data.

$$\text{NPV} = \sum_{t=0}^{T} \frac{1}{(1+r)^t} \left(\pi_t^2 - \pi_t^1\right),$$

where r is the appropriate discount rate.[5] Another useful measure of the value of switching from one activity to other is the Internal Rate of Return (IRR), which is the discount rate i such that

$$\sum_{t=0}^{T} \frac{1}{(1+i)^t} \left(\pi_t^2 - \pi_t^1\right) = 0.$$

The IRR is the highest rate of return that would make the proposed switch be profitable. This measure is particularly useful when the appropriate discount rate to use is uncertain.

The interpretation of the net benefit is similar in each case: it represents the net benefit or cost that actors would encounter in switching from the current, environmentally-degrading practice to the alternative, less damaging practice. Internalizing the effect of a negative externality such as environmental degradation will always reduce the measured return to an activity. The estimated net benefit, therefore, will generally be negative. It is interpreted as a cost of achieving the improvement in resource use or of complying with the standard to the agent undertaking the activity. These private costs of adopting the conserving activity are then compared to estimates of the social benefits that would be obtained from the resulting reduction in externalities. Since externalities are very difficult to quantify in practice, the costs of adopting the conserving activity are often compared to subjective judgements of the magnitude of the externalities to decide whether they are worth bearing.[6]

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[5] The choice of an appropriate discount rate has been the subject of considerable controversy since, given the inter-temporal nature of most natural and environmental resource problems, it will have a very significant effect on the results. This is not the place to plunge anew into the polemic over discount rates, which has been discussed extensively in numerous other places (see, *inter alia*, Pierce, Barbier, and Markandya [1990]). For the purpose of the discussion here, the most important point is that the discount rate used will depend on the purpose of the analysis. If the analysis is centered on examining the profitability of conservation from the farmers' viewpoint, then the appropriate discount rate to use is that actually faced by farmers. This is not as simple as it might sound, since farmers generally face highly imperfect capital markets. In practice, however, analysts often assume an arbitrary but plausible rate and then carry out sensitivity analysis. Where the purpose of the analysis is to calculate social profitability, then the appropriate discount rate to use is the best estimate of the social opportunity cost of capital.

[6] Note that if a decision is made that they are indeed worth bearing, difficult issues of implementation and income distribution will arise. Since these activities would impose net costs on private agents, they would not in general be adopted voluntarily. To achieve adoption might require either subsidies (in which case the net cost of switching to the conserving practice indicates the minimum required subsidy) or regulation (eg a standards approach). In the latter case, the private agents concerned will experience an income reduction equivalent to the net cost; where these agents are poor, such as in many developing country contexts, such distributive implications can be a cause of serious concern [Dasgupta and Mäler 1989].

When there are several possible alternative activities, they can all be compared in turn to the current activity. If all the alternative activities are equivalent from the point of view of environmental damage, this comparison allows the least-cost way of achieving a given reduction in damage to be found. On the other hand, if the activities differ in the amount of damage they cause, this comparison can provide an estimate of the cost of achieving different amounts of reduction in environmental damage.

3.2 The Policy Analysis Matrix

Cost-Benefit Analysis could be and has been extended to include the examination of the effect of divergences between private and social prices. Where the analysis of policy-induced distortions is of specific interest, however, the PAM provides a more specialized tool. Although it is also rooted in CBA, the PAM adds principles of trade policy to provide a convenient and illuminating way to categorize the various possible sources of distortion.

The PAM was designed to examine and compare the profitability of a given activity under observed, distorted prices and under social, 'efficiency' prices, and to identify the source of the distortions. Like CBA, the PAM is based on production budgets. Unlike CBA, however, PAMs do not compare two different activities, but rather the same activity using two different sets of prices. The structure of a PAM is shown in the top panel of Figure 9. On the top line, profitability is calculated in private terms, as experienced by economic agents; on the second line, profitability is calculated in social terms. The differences shown in the bottom line indicate the extent and source of divergences between the two. Specifically, the bottom right value indicates whether the net effect of the policy distortion is to implicitly transfer resources to (if the value is positive) or from (if the value is negative) the activity. For example, an activity that is privately profitable but socially unprofitable would be implicitly subsidized. The left-hand entries on the bottom row indicate the source of the divergences: it is possible, for example, for one policy—say, trade policy—to penalize an activity while another policy—say, domestic factor policy—encourages it. In principle, the social price line of a PAM corrects for both price distortions and market failures. For the purposes of the analysis developed here, however, it proves more convenient to treat the social price line of a PAM as correcting only for policy distortions.

The bottom panel of Figure 9 shows how observed data are used to construct a PAM, using the example of policy distortions already discussed in Figure 3. In this case, the private profitability of the activity is greater than its social profitability, so the net effect of policy distortions is to subsidize it. In practice, social prices are not in fact observed. Various ways exist to derive the required social prices [Monke and Pearson, 1989]. Since, in practice, the optimal activity level at social prices, L^S, is also unobservable, the current activity level is generally used, so that cell E (social revenues), for example, is estimated as being approximately $R^S[L^P]$.[7] It must be stressed that these are not weaknesses of the method *per*

[7] This implies that transfers *to* producers are *over*-estimated while transfers from producers are *under*-estimated.

	Revenues	Costs: Tradables	Costs: Non-Tradables	Profits
Private Prices	A	B	C	D
Social Prices	E	F	G	H
Divergences	I	J	K	L

D = A - B - C; H = E - F - G;
I = A - E; J = B - F; K = C - G;
L = D - H = I - J - K

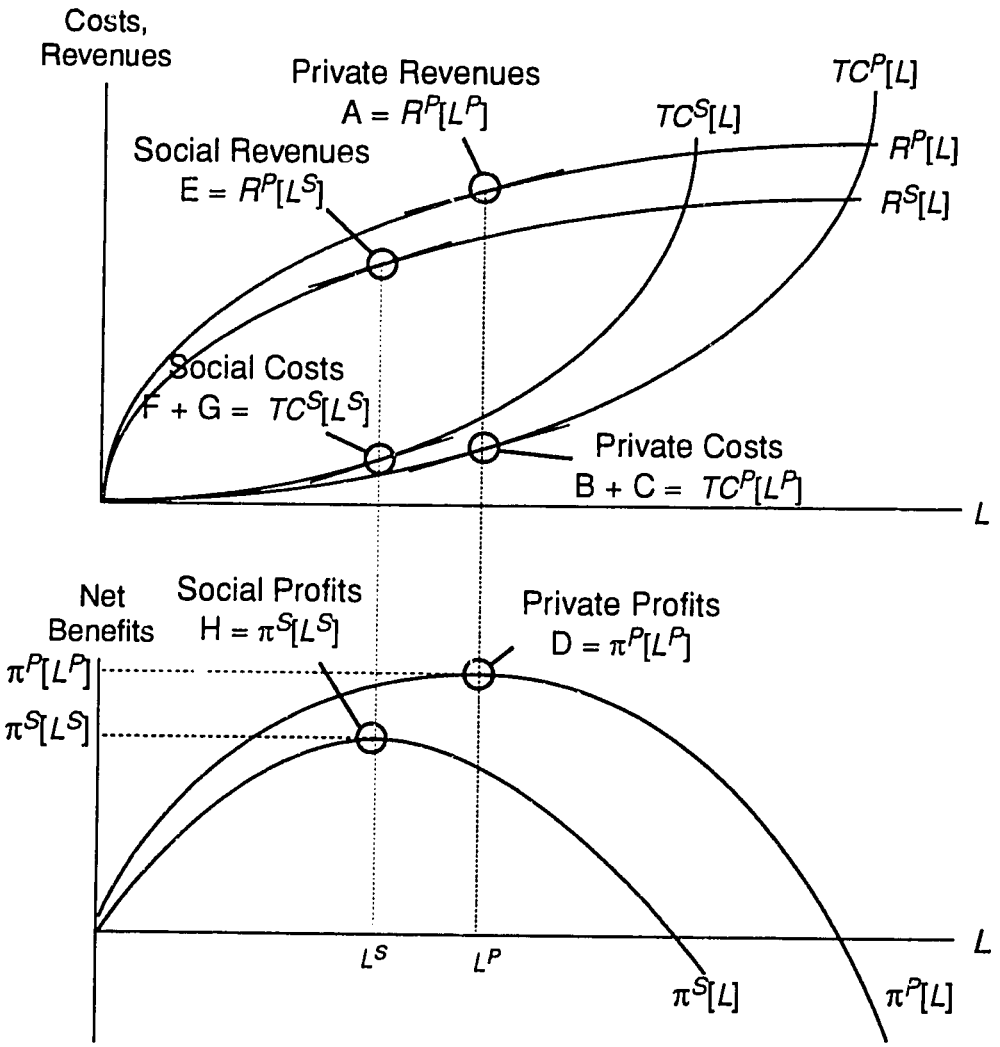

Figure 9. Policy Analysis Matrix and Source of Budget Data for its Construction

se but rather of the data usually available. Given better data, such approximations can be avoided. Other techniques to estimate the magnitude and effects of policy distortions are generally even more demanding of data.

3.3 Integrating Cost-Benefit Analysis and Policy Analysis

Given the strengths of CBA and PAM analysis in examining the market failure and policy distortion aspects of resource problems, respectively, combining them offers promise of achieving a more integrated and complete analysis of such problems. Fortunately, combining them is straight-forward since both are at their core based on activity budgets.

Figure 10 shows a combined PAM and CBA matrix for the analysis of a resource problem, formulated here as a choice between a degrading and a conserving activity. The degrading activity (denoted by superscript D) is the current activity; it is assumed to cause some external damage in addition to the direct costs and benefits which are quantified in the budgets. The conserving activity (denoted by superscript C) is assumed to cause less such damage; it can be thought of either as an approximation to the optimal activity that would be observed if externalities were internalized or as a standard imposed to achieve a specific environmental objective. The CBA part of the analysis is read horizontally across the CBA/PAM matrix, the PAM analysis vertically. Essentially, the CBA/PAM matrix consists of two side-by-side PAMs, one for the degrading and one for the conserving activity, and two CBA calculations on the net benefits of adopting the conserving activity, one in private prices and one in social prices. The lower panel of Figure 10 locates the various elements of the comparison on the graphical analysis performed earlier.

Within each CBA and PAM section, traditional interpretations remain valid. By juxtaposing the PAM and the CBA analyses, however, additional information and insights can be acquired. Consider, for example, an externality situation in which the conserving activity seeks to reduce the external damage caused by the degrading activity, for example by imposing a standard that limits its extent. In this case, complying with the standard is likely to impose costs on the agents undertaking the activity, so that the net private benefit of switching to the conserving activity is negative. This cost of compliance could be compared to the estimated costs of the external damage to decide whether the costs are worth bearing. Since prices are distorted by policy interventions, however, the NPB does not indicate the real cost to society of reducing the external damage to the level set by the standard. By recalculating these costs in social terms, a much better estimate is obtained. The criterion, then, would be to impose the standard if the social costs of compliance (ie the NSB) are judged to be lower than the value of the reduction in external damage caused. The NPB would still indicate the cost of compliance borne by private actors, and hence provide an estimate of the income impact of imposing the standard and/or the minimum subsidy required to ensure voluntary adoption.

Comparing the private and social profitabilities of the two activities would indicate the degree to which policy distortions are responsible for the degrading activity being engaged in.

	Degrading Activity			Conserving Activity			
	Revenues	Costs	Profits	Revenues	Costs	Profits	
Private Prices	A^D $R^{DP}[L^{DP}]$	B^D+C^D $PC^{DP}[L^{DP}]$	D^D $\pi^{DP}[L^{DP}]$	A^C $R^{CP}[L^{CP}]$	B^C+C^C $TC^{CP}[L^{CP}]$	D^C $\pi^{CP}[L^{CP}]$	Net Private Benefits $NPB = D^C - D^D$
Social Prices	E^D $R^{DS}[L^{DS}]$	F^D+G^D $PC^{DS}[L^{DS}]$	H^D $\pi^{DS}[L^{DS}]$	E^C $R^{CS}[L^{CS}]$	F^C+G^C $TC^{CS}[L^{CS}]$	H^C $\pi^{CS}[L^{CS}]$	Net Social Benefits $NSB = H^C - H^D$
Divergences	I^D Output Transfers	J^D+K^D Input Transfers	L^D Net Transfers	I^C Output Transfers	J^C+K^C Input Transfers	L^C Net Transfers	Net Transfers to Conservation $NTC = NPB - NSB$

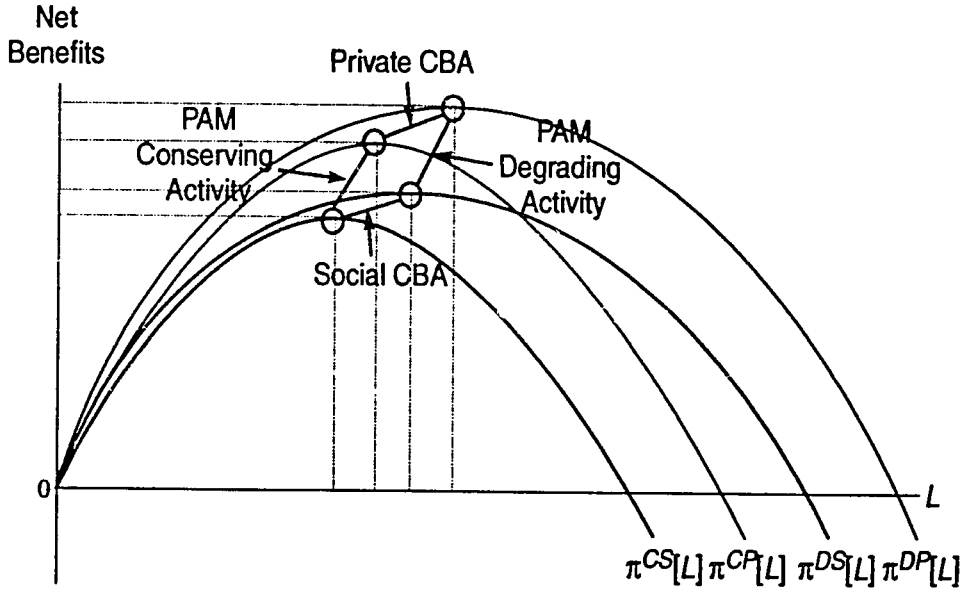

Figure 10. Combined PAM and CBA Matrix for the Analysis of Environmental and Natural Resource Problems Involving Market Failures and Policy Distortions

The value calculated for *net transfers to conservation* (bottom right cell) indicates whether policy tends to encourage conservation over degradation or not. This value is calculated either as the difference between net transfers to the degrading and the conserving activities or as the difference between the net private and social benefits to switching to the conservation activity, both of which give the identical result, as can be verified from Figure 10. If this value is positive, it indicates that the net effect of policy distortions is to favor the conserving activity compared to the degrading activity. Note that this does not imply that it is favored in an absolute sense—indeed, both activities might be highly taxed, in which case a positive net transfer to conservation implies the conserving activity is less taxed.[8] Distortions would be particularly pernicious if they made a socially unprofitable degrading activity appear to be privately profitable and/or a socially profitable conserving activity appear to be privately unprofitable. If such cases are encountered, they would represent 'win-win' cases in which removing distortions would also reduce the mis-use of resources.[9]

It is not uncommon to find that policies counteract each other to some degree. As in all PAM analysis, the source or sources of the divergence can be identified from the disaggregation of revenue and cost categories. Here too, the difference between, say, distortions on tradable costs across the two activities indicate the degree to which trade policy preferentially affects one or the other activity. Since policies serve many non-efficiency objectives in addition to efficiency objectives, it may not in practice be realistic to expect that all policy distortions could be removed, even to correct very pernicious cases. The detailed disaggregation of policy effects provided by the PAM would be particularly useful in such instances by allowing the most important sources of the divergence to be identified. Alternately, the analysis could be conducted using social prices that would result if only a specific sub-set of policy distortions were removed.

For ease of exposition, both the CBA and the PAM matrices have been shown as if they were single-period constructs. The method is readily extended to a multi-period framework. Before doing so, however, it is worth noting that there are cases where a single-period framework is appropriate. The most obvious such case would arise if both the degrading and the conserving activity remain constant over time and the external damage caused by the degrading activity (which would be wholly or partially abated by the conserving activity) has no inter-temporal links. The purest example would be noise, which inflicts an external cost only while it is actually being generated. The external damage drops

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[8] Note that the result that government policy discourages conservation (say) is only valid for the specific pair of activities being compared. Other conserving activities might be encouraged by distortions. Only if a net transfer away from conservation is found in comparing numerous such pairs can a more general conclusion that policy tends to discourage conservation in general be reached.

[9] Note, however, that economic actors would not necessarily switch to the conserving activity if the distortions were removed and the degrading activity become unprofitable, since the specific conserving activity being examined is only one of many possible alternative activities. In particular, they might switch to another degrading activity if that is their next most profitable alternative at the new prices.

to zero as soon as the activity ceases, and does not accumulate. In this case, the costs and returns to each activity would not vary from period to period and the problem can be handled in a single-period framework, with any initial costs of switching to the conserving activities are depreciated over a suitable time period.

As soon as any kind of inter-temporal linkage is introduced, however, a single-period CBA/PAM becomes inappropriate. Such linkages might arise either because the external damage caused by the degrading activity is cumulative, or because the activities change over time. Soil conservation problems, for example, clearly require an inter-temporal approach because yields and costs are unlikely to remain constant under either the degrading or the conserving activity and the external damage—typically, sedimentation of reservoirs—is cumulative.

Two approaches are possible to introducing a time element into a CBA/PAM matrix. The simplest is to treat the value of each cell as the net present value of the values in each period over the period of analysis. Thus in the cell for private revenues under the degrading activity, previously shown as $\pi^D[L^{DP}]$, we would have $\sum \rho^t \pi^D_t[L^{DP}_t]$, where ρ is a discount factor and the subscripts t indicate the time period. The second approach involves linking a sequence of CBA/PAM matrices, one for each time period. For an application of this approach, see Jansen. Time would thus become a third dimension to the two already present in the matrix. A summary matrix providing the net present values for each cell could also be prepared, of course, and would give identical results to that prepared under the first method. This second method would, however, provide an explicit time path for each of the variables. Collapsing all time periods into a single net present value would obscure such paths. As the values of the technical coefficients change over time, both the net benefits of conservation and the relative impact of policy distortions will vary. Some policy distortions, for example, might have a small total effect over the entire period of analysis but be critical at certain periods. Likewise, a positive net present value for the net benefits of conservation might hide long periods in which this value is negative.

4. CONCLUSIONS

The interaction between market failures and policy distortions causes significant problems, both conceptual and empirical, in the analysis of resource problems. The combination of CBA and PAM analysis proposed here has considerable potential in helping examine these problems.

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