Exploring production-theoretical insights for economic-ecological trade-off analysis

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Abstract

This paper provides a framework for analyzing economic-ecological trade-off measures at firm level. This must allow for distinguishing different stages in the trade-off curve. Based on a literature review, various economic-ecological trade-off paradigms and theories are combined, and integrated and additive measures are distinguished. While integrated measures address input-output transformation and the relation with negative externalities and profit generation, additive measures aim at pollution abatement after externalities have already been generated. Since additive measures are costly, they always imply a negative trade-off, improving ecological performance and diminishing economic performance. Some integrated measures imply a positive trade-off, improving both economic and ecological performance. In order to analyze trade-off measures, production-theoretical foundations of input-output transformation and the link with economic and ecological performance are elaborated. Production, profit and emission functions that are theoretically consistent are constructed, taking into account the materials balance principle for pollution. These theoretical underpinnings serve as basis for establishing a framework for trade-off analysis. The framework shows that not all measures have straightforward trade-off implications. Trade-off implications of some integrated measures may be positive or negative, depending on the input-output technology of the firm, the combination of input(s) and output(s) that the firm is currently using and the prices and ecological coefficients of input(s) and output(s).

Keywords: economic-ecological trade-off, production theory, emission function, materials balance principle

1. Introduction

Decision making becomes more and more complex for firms. On the one hand, firms have to keep competitive under strengthening competition. On the other hand, the internalization of ecological effects forces firms to take into account ecological performance. Maintaining competitiveness in harmony with the environment is one of the major challenges for firms.

In order to provide better guidance for improving economic and/or ecological performance, the trade-off between both performances has to be explored. Trade-offs can be positive or negative. A positive trade-off implies that economic and ecological performance improve simultaneously. A negative trade-off implies that economic performance improves, while ecological performance diminishes or vice-versa.

The objective of this paper is to provide a framework for economic-ecological trade-off analysis. Production-theoretical foundations of transforming input into output are elaborated, together with their relation with economic and ecological performance. The framework allows for distinguishing different stages in the trade-off curve. This provides a reference basis for evaluating in a consistent manner the effect of different types of measures influencing economic and/or ecological performance.

In section 2, based on a literature review, various economic-ecological trade-off paradigms and theories are combined and integrated and additive measures are distinguished. Section 3 explores production-theoretical underpinnings that allow for linking production with economic and ecological performance. Based on these production-theoretical underpinnings, a framework is provided in section 4 that allows for analyzing the distinguished trade-off measures at firm level. Section 5 concludes.

2. Combining trade-off paradigms and theories

Typically, the trade-off between economic and ecological performance is presented by the marginal abatement cost (MAC) curve. The MAC curve links a firm's emission level to the cost of additional units of emission reduction (McKitrick, 1998).

Conventional theory bases the MAC curve on the assumptions that production and pollution abatement are separable and actual production is efficient. These assumptions imply that a firm can control its emission by either investing in pollution control equipment or by reducing output. Emission is considered as a fixed proportion of a firm's output. This strict joint production relation (Whitcomb, 1972) implies weak disposability for negative externalities. Weak disposability only allows for a proportional reduction of outputs and pollution (Shephard, 1970). A decrease of only negative externalities is then always costly. Conventional theory therefore always assumes a negative trade-off between economic and ecological performance. A better economic performance brings along a worse ecological performance and vice versa.

Constructing the MAC curve based on conventional theory has been criticized by numerous authors (e.g. Archibald (1988), Hill et al. (1999), Rennings (2000), Wossink et al. (2001), Wossink and Denaux Sogutlu (2002)) . Wossink et al. (2001) argue that production, pollution and abatement are to be treated as non-separable. This allows for proper account to be taken of control options provided by changes in production practices. Negative externalities most often result from specific inputs that have the characteristics of joint inputs, as any quantity simultaneously produces the intended output and the unintended externality. The combination in which these marketable outputs and bad side effects is generated depends on the production method chosen – this combination is not fixed. It is often technically feasible to substitute inputs or introduce new production processes or inputs to reduce the level of the externality without reducing the level of planned output.

Archibald (1988) states that strict joint production specifications do not allow for the technical possibilities of abatement of negative externalities and provide too little flexibility to describe accurately externalities from production. Sudit and Whitcomb (1976) present a so-called generalized joint production model that allows for (a) both intended outputs and unintended externalities to be produced, (b) their proportion to be varied, and (c) possibilities of rearrangement of productive inputs to counter negative externalities.

Wossink and Denaux Sogutlu (2002) show that efficiency improvements can offset (part of) the costs associated with better ecological quality of production. De Koeijer et al. (1999) argue that using inputs more efficiently may lead to the achievement of both economic and ecological objectives simultaneously. This implies that negative externalities cannot always be considered as weakly disposable, meaning that ecological improvement does not have to come at a private cost. If economic and ecological performances improve simultaneously, a positive trade-off is established.

So, conventional assumptions underlying abatement cost analysis provide too little flexibility to describe accurately the process of firm level transition to ecologically sound production practices and how this influences abatement costs. Hill et al. (1999) distinguish three main stages in the process of farm level transition to ecologically sound production practices: (1) efficiency improvement, (2) substitution of inputs or production processes and (3) redesign, that is, output reduction or the use of new or additive technology for ecological purposes. Similarly, Rennings (2000) distinguishes between integrated and additive measures. Integrated measures directly address the cause of emissions during the production process, while additive measures are end-of-pipe oriented and occur after actual production.

For our research, we also distinguish between integrated and additive measures. While Rennings (2000) only considers measures that aim at improving ecological performance, economic-ecological trade-off analysis also requires considering measures that improve economic performance but diminish or do not affect ecological performance.

Additive measures aim at pollution abatement after externalities have already been generated. These measures are always costly and therefore imply a negative economic-ecological trade-off. Integrated measures address input-output transformation and the relation with externality and profit generation. These measures include efficiency improvement, scale adaptation, re-arrangement of productive inputs, introducing ecological friendly inputs, using cheaper inputs and improving output quality in order to obtain higher output prices. Integrated measures may imply a positive or negative trade-off.

Some trade-off measures may have a time span that goes beyond operational and tactical decisions. Those measures lead to changes in the firm’s structure and can be considered as strategic actions (Das, 1991). Firms perform strategic actions to take advantage of external opportunities and to avoid or reduce the impact of external threats (David, 1998). Strategic actions allow for maintaining or strengthening positions in a competitive sector. Since ecological side-effects were not really an issue to the firm’s operation and planning in the past, strategic actions were not, or scarcely, determined by ecological externalities.

This may change when policy actions or market signals for cleaner production internalize external effects. The revisionists and the Porter hypothesis (Porter and van der Linde, 1995) argue that properly designed ecological regulations trigger the innovation potential that may partially or more than fully offset the costs of complying with them. Contrarily, conventional economists argue that stringent ecological regulations inevitably raise costs and cause slow productivity growth by diverting capital resources away from other, more productive investments (Palmer et al., 1995).

3. Linking production to economics and pollution

Given the nature of the distinguished trade-off measures, an analyzing framework has to be based on the linkage between production, economic and ecological performance. Figure 1 presents a one input-one output production function that represents the production technology of a particular firm. The S-shaped production function is based on the Von Liebig-Mitscherlich law of varying returns to increasing input use. The firm uses Xf input to produce Yf output. If input and output prices are known, (marginal) cost and (marginal) revenue functions that are consistent with the production function can be derived. In figure 1, the marginal cost function in the short run is presented and the assumed perfect competition implies that marginal revenues equal output price. The economic performance of the firm is represented by the shaded area between the marginal revenue and the marginal cost function up to its output level.

Figure 1 Production and economic performance

The question rises how to integrate ecological performance in this framework. A majority of studies have approached the integration problem by incorporating an extra pollution variable into the production model, either as another input or as a weakly disposable bad output (see reviews by Tyteca (1996) and Scheel (2001)). A detailed discussion about the treatment of these variables as inputs or as undesired outputs falls beyond the scope of this paper. However, as discussed in section 2, pollution has not always to be seen as weakly disposable. Moreover, a number of authors (e.g. Pethig (2006), Coelli et al. (2007), Ebert and Welsch (2007)) argue that some of these approaches are inconsistent with the materials balance condition.

It is difficult for one to conceptualize a production system in which a materials balance condition does not apply to the pollution variable (Pethig, 2006). Due to the first law in thermodynamics, which is the law of mass conservation, the transformation of material inputs to desired outputs can never be complete: some residual inadvertently arises as a by-product, and material input, desirable output, and residual are linked by the material balance (Ebert and Welsch, 2007):

(1) $R = CoefX \times X - CoefY \times Y$

where R = residual matter (kg), CoefX = incoming quantity per material input X (kg/kg), CoefY = outgoing quantity per desirable output Y (kg/kg)

So, the amount of residual matter is calculated by linking ecological coefficients to input and output, in a similar way that economic performance is calculated by linking price coefficients to input and output. Therefore, once the ecological coefficients and the production function are known, corresponding functions that represent (marginal) incoming quantities in input and (marginal) outgoing quantities in output in relation to output can be derived. Figure 2 shows marginal pollution, as the difference between the marginal incoming quantity in input and the marginal outgoing quantity in output, in consistency with the S-shaped production function for the considered firm. The ecological performance is represented by the shaded area that adds up marginal pollution up to the output level of the firm.

Figure 2 Production and ecological performance

Although there exists a minimum marginal pollution at a certain output level, marginal pollution is always positive. Producing more output with a given production technology implies more pollution. The explanation is based on the second law of thermodynamics, being the entropy law, which, according to Baumgärtner et al. (2001), implies that any incremental unit of material input can only incompletely be transformed into desired output:

$$(2) \qquad \frac{dR}{dX} > 0$$

If we apply equation (2), by Baumgärtner et al. (2001), to equation (1), we obtain:

$$(3) \qquad CoefX - CoefY \times \frac{dY}{dX} > 0$$

Multiplying left and right hand side with $\frac{dX}{dY}$, which is positive if we consider marginal product to be positive, yields:

$$(4) \qquad CoefX \times \frac{dX}{dY} - CoefY > 0$$

The left hand side of equation (4) equals the first derivative of equation (1) with respect to Y and therefore represents marginal pollution. Consequently, under the condition of a positive marginal product, marginal pollution is also positive. If output increases, pollution will also increase.

4. Economic-ecological trade-off framework

Now that we have constructed a clear relation between production, economic and ecological performance, we can integrate the distinguished trade-off measures into a framework. Since additive measures aim at pollution abatement after externalities have already been generated, no special attention is needed for integrating these measures into the framework.

Additive measures are always costly and imply a negative economic-ecological trade-off. In the following sections, we concentrate on the integrated measures.

4.1. Efficiency improvement and input re-arrangement

Efficiency measurement is mainly based on the work by Farrell (1957), who states that the efficiency of an entity consists of two components: technical efficiency, which, from an input oriented viewpoint, reflects the ability to use minimal input(s) to obtain (a) given output(s), and cost allocative efficiency, which reflects the ability to use inputs in optimal proportions, given their respective prices and the production technology. Input oriented technical and cost allocative efficiency can be combined to provide a measure of cost efficiency. From an output oriented viewpoint, technical efficiency reflects the ability to obtain maximal output(s) with given input(s).

Coelli et al. (2007) incorporate the materials balance concept for negative externalities into efficiency measurement. In a similar manner to the conventional cost efficiency decomposition, an ecological efficiency measure is defined that can be decomposed into technical and allocative components.

Figure 3 presents two unit-isoquants in an input-input space[1]. A unit-isoquant presents input substitution possibilities for producing one unit of output. Given the input prices, there is a combination of inputs on each unit-isoquant that maximizes economic performance. Similarly, given their ecological coefficients, there is an input combination that maximizes ecological performance. The economic optimal input combination is located where the proportion of input prices equals the marginal substitution rate of inputs. Similarly, the ecological optimal input combination is located where the proportion of ecological coefficients of inputs equals their marginal substitution rate.

The upper unit-isoquant represents the production technology of a firm that currently uses input quantities X1f and X2f to produce one unit of output. Substituting X1 by X2 (path 1) results in an input allocation that yields a better economic and a better ecological performance, and therefore implies a positive trade-off. Beyond the input combination that maximizes economic performance, further substitution of X1 by X2 (path 2) diminishes economic performance but improves ecological performance and therefore implies a negative trade-off.

Trade-offs established under paths 1 and 2 imply that the technology of the firm does not change. Hazell and Norton (1986) call this a change in technique. The production function, and therefore also the unit-isoquant, remain the same. Changes in technology imply an altering production function.

Figure 3 Trade-offs through efficiency improvement and input substitution

The lower unit-isoquant represents a fully technical efficient production technology and is called production frontier. The firm can move towards the frontier by improving its technical efficiency, i.e. by using less inputs per unit of output. This can be achieved through adopting new production technologies or improving management of the firm. If the firm improves its technical efficiency (path 3), its economic as well as ecological performance increases, yielding a positive trade-off. Once arrived on the frontier, the firm is able to further allocate inputs. By following path 4, a positive economic-ecological trade-off is established. Path 5 then implies a negative trade-off, improving ecological performance but diminishing economic performance.

In figure 3, two parallel unit-isoquants are presented. However, the adoption of a new production technology does not necessarily yield a unit-isoquant that is parallel to the original one. If the slope of the unit-isoquant changes, economic and ecological optimal input combinations will also change. Consequently, trade-off paths may differ under different technologies. Using new production technologies may also imply that other or additive inputs are used, with their own prices and ecological coefficients. In that case, new optimal input combinations arise and trade-off paths will change.

4.2. Scale adaptation

In the long run, firms can optimize their economic scale. At optimal scale and under perfect competition, long term marginal costs equal long term marginal revenues and average costs. Above optimal scale, marginal costs for producing one unit of output more exceed marginal revenues. Below optimal scale, marginal costs are lower than marginal revenues. Figure 4 shows for a firm its optimal scale, which lies at output level Ys.

Figure 4 Trade-offs through scale adaptation

First, suppose that the firm produces less than Ys output. In that case, economic performance can be improved by increasing the output level. However, more output implies that pollution also increases, since marginal pollution is always positive. Consequently, exploiting economies of scale through increasing output implies a negative economic-ecological trade-off. Second, suppose that the firm produces more than Ys output. Now, economic performnce can increase by decreasing the output level. A lower output level implies less pollution. Therefore, decreasing scale towards optimal scale implies a positive economic-ecological trade-off.

4.3. Using cheaper or ecological friendly inputs

Input combinations that maximize economic and ecological performance depend amongst other things on the proportion of, respectively, input prices and ecological coefficients of inputs (see section 4.2.). However, economic or ecological performance is not only determined by the proportion of these prices or ecological coefficients.

If a firm, for example, uses the same inputs but purchases them at lower prices, price proportions and consequently, profit maximizing input combinations, might be the same, but nevertheless, economic performance is much better. Buying the same inputs at lower prices therefore improves economic performance, without affecting ecological performance. Similarly, if a firm uses the same inputs, but with lower ecological coefficients, its ecological performance improves while economic performance does not change.

4.4. Improving output quality

Firms may also choose for improving the quality of output, in order to obtain higher output prices. As long as a quality improvement does not require the use of more, other or additional inputs, this measure improves economic performance without influencing ecological performance. If more, other or additional inputs are used for improving output quality, this corresponds to the adoption of a new technology and economic as well as ecological performance may change.

5. Conclusion

In order to construct a framework for assessing economic-ecological trade-offs, a clear link between input-output transformation, economic and ecological performance has to be established. Production, profit and emission functions that are theoretically consistent must be constructed, taking into account the materials balance principle for pollution.

Trade-off measures consist of additive and integrated measures. Integrated measures address input-output transformation and the relation with externality and profit generation, while additive measures aim at pollution abatement after externalities have already been generated. Additive measures are always costly and imply a negative economic-ecological trade-off, improving ecological performance and diminishing economic performance.

Integrated measures, however, may also result in a positive economic-ecological trade-off, improving both economic and ecological performance. Technical efficiency improvement, for example, always implies a positive trade-off. Input substitution implies a positive or negative trade-off, depending on the input-output technology of the firm, the input combination the firm is currently using and the proportions of respectively input prices and ecological coefficients of inputs.

Increasing scale always diminishes ecological performance and vice versa. If a firm is currently operating below economic optimal scale, increasing scale leads to a negative economic-ecological trade-off. If a firm is currently operating above economic optimal scale, decreasing scale results in a positive economic-ecological trade-off.

Certain measures may improve economic performance, without affecting ecological performance. These measures consist of improving output quality and buying the same inputs at lower prices. On the contrary, using the same inputs, but with lower ecological coefficients (i.e. ecological friendly inputs), results in a better ecological performance without influencing economic performance.

References

Archibald, S.O. (1988). Incorporating externalities into agricultural productivity analysis. In: Capalbo, S.M. and Antle, J.M. (Eds.) Agricultural productivity: measurement and explanation. Resources for the future, Washington, 366-393.

Baumgärtner, S., Dyckhoff, H., Faber, M., Proops, J. and Schiller, J. (2001). The concept of joint production and ecological economics. Ecological Economics, 36, 365–372.

Coelli, T., Lauwers, L. and Van Huylenbroeck, G. (2007). Environmental efficiency measurement and the materials balance condition. Journal of Productivity Analysis, 28, 3-12.

Das, T.K. (1991). Time: the hidden dimension in strategic planning. Long Range Planning, 24, 49-57.

David, F.R. (1998). Strategic management: concepts and cases. Francis Marion University.

De Koeijer, T. J., Wossink, G. A. A., van Ittersum, M. K., Struik, P. C. and Renkema, J. A. (1999). A conceptual model for analysing input-output coefficients in arable farming systems: from diagnosis towards design. Agricultural Systems, 61, 33-44.

Ebert, U. and Welsch, H. (2007). Environmental emissions and production economics: implications of the materials balance. American Journal of Agricultural Economics, 89, 287-293.

Farrell, M.J. (1957). The measurement of productive efficiency. Journal of the Royal Statistical Society, 120, 253-281.

Hazell, P.B.R. and Norton, R.D. (1986). Mathematical programming for economic analysis in agriculture. New York, MacMillan Publishing Company.

Hill, S.B., Vincent, C. and Chouinard, G. (1999). Evolving ecosystems approaches to fruit insect pest management. Agriculture, Ecosystems and Environment, 73, 107-110.

McKitrick, R. (2002). A derivation of the marginal abatement cost curve. Journal of Environmental Economics and Management, 37, 306-314.

Palmer, K., Oates, W.E. and Portney, P.R. (1995). Tightening environmental standards: the benefit-cost or the no-cost paradigm? Journal of Economic Perspectives, 9(4), 119-132.

Pethig, R. (2006). Nonlinear production, abatement, pollution and materials balance reconsidered. Journal of Environmental Economics and Management, 51, 185-204.

Porter, M.E. and van der Linde, C. (1995). Toward a new conception of the environment competitiveness relationship. Journal of Economic Perspectives, 9(4), 97-118.

Rennings, K. (2000). Redefining innovation - eco-innovation research and the contribution from ecological economics. Ecological Economics, 32, 319-332.

Scheel, H. (2001). Undesirable outputs in efficiency valuations. European Journal of Operational Research, 132, 400-410.

Shepard, R. W. (1970). Theory of cost and production functions. Princeton, Princeton University Press.

Sudit, E. F. and Whitcomb, D. K. (1976). Externality production functions. In: Lin, S.A.Y. (Ed.) Theory and measurement of economic externalities. Academic Press, New York, 247-257.

Tyteca, D. (1996). On the measurement of the environmental performance of firms - a literature review and a productive efficiency perspective. Journal of Environmental Management, 46, 281-308.

Whitcomb, D. K. (1972). Externalities and welfare. New York, Columbia University Press.

Wossink, A. and Denaux Sogutlu, Z. (2002). Environmental efficiency, separability and abatement costs of nonpoint-source pollution. Paper presented at the annual meeting of the AAEA, 2002, Long Beach CA, United States.

Wossink, G. A. A., Oude Lansink, A. G. J. M. and Struik, P. C. (2001). Non-separability and heterogeneity in integrated agronomic-economic analysis of nonpoint-source pollution. Ecological Economics, 38, 345-357.

Footnotes

[1] A unit-isoquant framework is only valid under constant returns to scale. However, for clarifying purposes, unit-isoquants are used here.

Figure Captions

Figure 1 Production and economic performance

Figure 2 Production and ecological performance

Figure 3 Trade-offs through efficiency improvement and input substitution

Figure 4 Trade-offs through scale adaptation

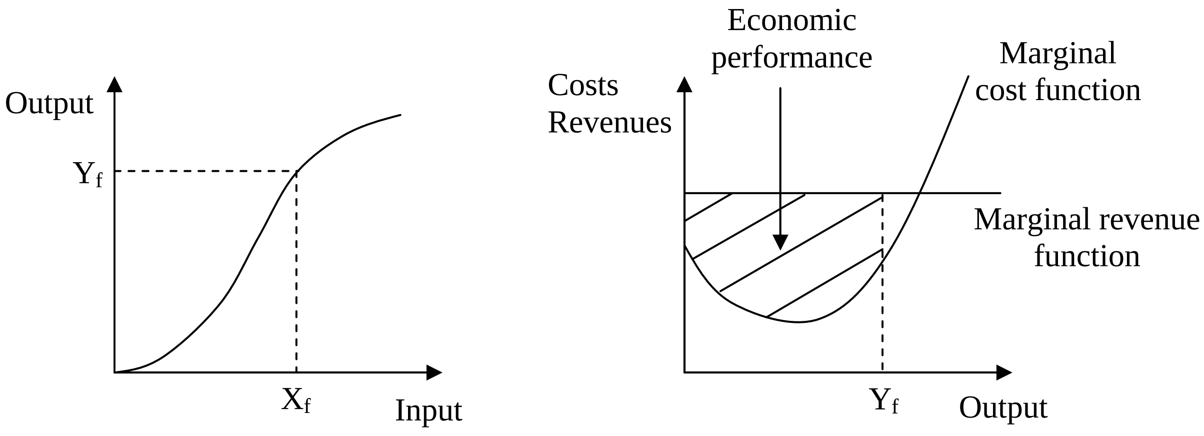

Figure 1 Production and short run economic performance

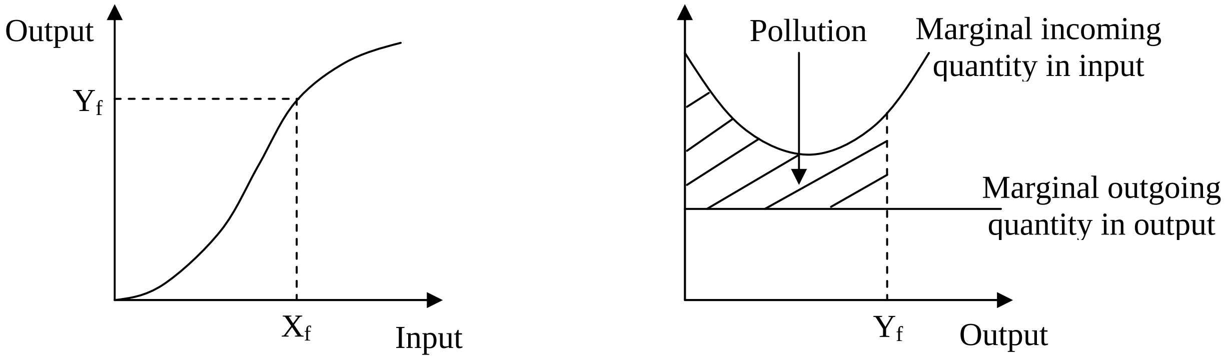

Figure 2 Production and ecological performance

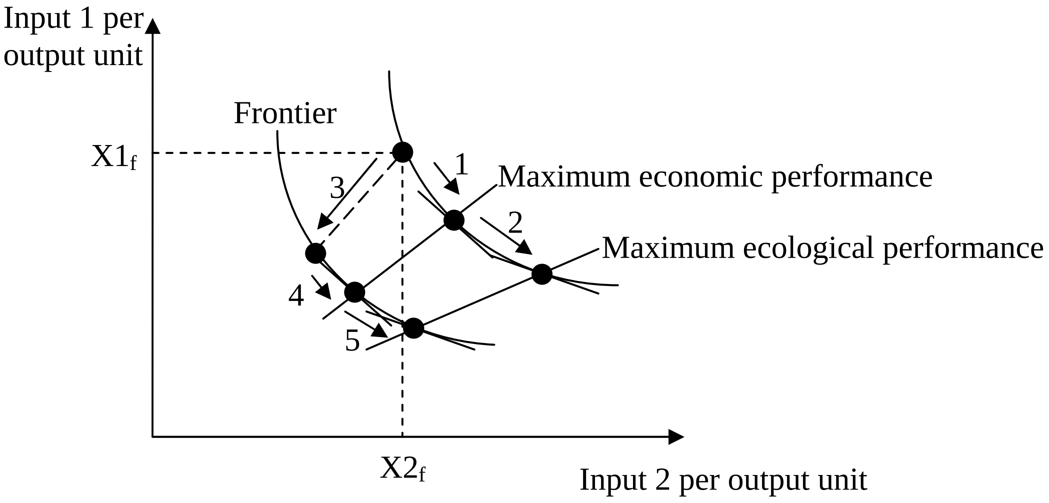

Figure 3 Trade-offs through efficiency improvement and input substitution

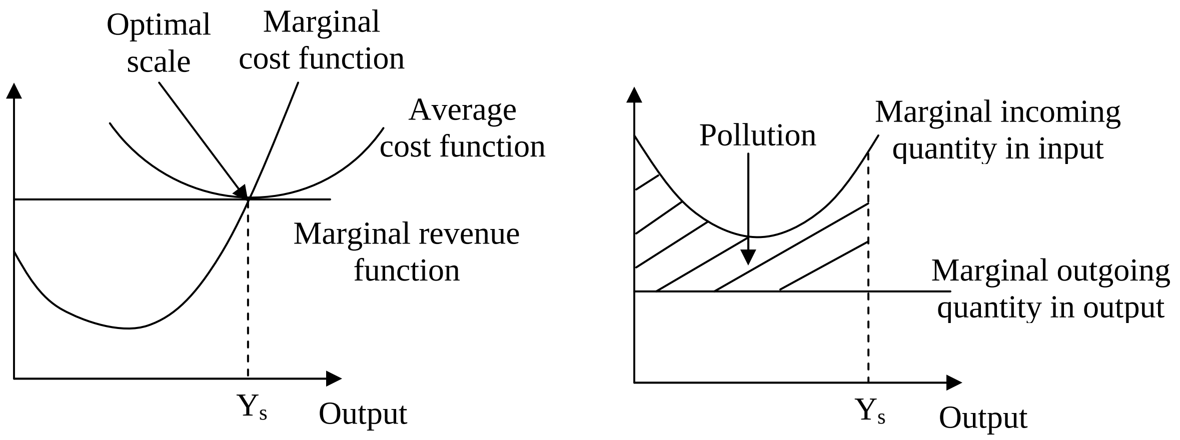

Figure 4 Trade-offs through scale adaptation