Exploring production-theoretical insights for analyzing trade-offs between economic performance and environmental pressure at firm level

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Abstract

The objective of this paper is to construct a framework for analyzing trade-offs between economic performance and environmental pressure at firm level. Based on a literature review, partially conflicting economic-environmental trade-off paradigms are structured and five necessary conditions for adequate trade-off analysis are put forward. These conditions are delimitating a clear system for which trade-offs are analyzed, assessing the direction of causality between economic performance and environmental pressure, allowing for firm-specific trade-off differences, comprehensiveness with respect to management activities that can be evaluated and flexibility to analyze trade-offs under different market and environmental regulation conditions. To deal with the causality condition, theoretically consistent production, cost, revenue and emission functions are constructed, taking into account the materials balance principle for emission. The linkage between production, economic performance and environmental pressure is then used to construct a framework that integrates the five necessary conditions for trade-off analysis. Our theoretical elaboration shows that economic-environmental implications are firm-specific and depend on the management activity that is applied, on market conditions and on environmental regulation conditions. Theoretically, both pollution prevention and end-of-pipe measures may yield positive or negative economic-environmental trade-offs. Economic-environmental implications of different management activities represent different stages in the trade-off curve. In fact, the partially conflicting trade-off paradigms in literature are also different stages in the trade-off curve. At the end of this paper, some recommendations are given for making the framework operational.

1. Introduction

Societal concerns about the negative environmental effects of firm activities have led to a sharp increase of environmental regulations around the world (Rugman and Verbeke, 1998). Government regulations represent the most important incentive for firms to consider environmental issues (Henriques and Sadorski, 1996). But firms also need to remain competitive under difficult market conditions. Decision making, therefore, becomes more and more complex for firms. Maintaining competitiveness in harmony with the environment is one of the major challenges for firms.

In order to provide firms with better guidance for improving economic performance and reducing environmental pressure, economic-environmental trade-offs have to be explored. Trade-offs can be positive or negative. A positive trade-off implies that economic and environmental performances improve simultaneously. A negative trade-off implies that economic performance improves, while environmental performance diminishes or vice-versa.

Literature on economic-environmental trade-offs is abundant but not conclusive. Theoretical paradigms are partially conflicting in the sense that there is no agreement on the existence of positive trade-offs. There is also significant variation across empirical studies, ranging from negative to positive trade-offs identified. Therefore, the challenge is to construct a generalizing framework to help firms with their decision making on improving economic performance and reducing environmental pressure.

The objective of this paper is to construct a framework for analyzing trade-offs between economic performance and environmental pressure at firm level. The framework must provide a reference basis for evaluating in a consistent manner the effect of different types of measures influencing economic and/or environmental performance. In that way, different stages in the trade-off curve can be distinguished.

Based on a literature review, section 2 structures partially conflicting economic-environmental trade-off paradigms and puts forward necessary conditions for adequate trade-off analysis. Section 3 further elaborates on the condition that the direction of causality between economic performance and environmental pressure has to be assessed. Production-theoretical foundations of transforming inputs into outputs are elaborated, together with their relation with economic performance and environmental pressure. Section 4 then integrates the necessary conditions into a framework that allows for analyzing firm-specific economic-environmental implications of different management activities under different market and environmental regulation conditions. Finally, section 5 concludes and gives some recommendations for making the framework operational.

2. Literature review on economic-environmental trade-offs

Firm-specific trade-offs between economic performance and environmental pressure become important when environmental effects are internalized. Internalization of externalities attributes external costs to firms that are not reflected in the price of production. In order to reduce these additional costs, a clear view on the relationship between economic and environmental performance is indispensable. This section structures the partially conflicting paradigms on economic-environmental trade-off in literature and puts forward necessary conditions for adequate trade-off analysis.

2.1. Structuring partially conflicting trade-off paradigms

The relationship between economic and environmental pressure of firms has been studied in literature for a considerable period of time. In general, two perspectives have emerged: while conventional theory assumes a relationship between economic and environmental performance that is uniformly negative, the revisionist hypothesis proposes an inversely U-shaped curve with a positive link at lower environmental performance levels and a negative link at higher levels (Schaltegger and Synnestvedt (2002), Wagner (2003), Wagner (2005), Claver et al. (2007), Boons and Wagner (2009)).

Conventional theory bases the negative relationship between economic and environmental performance on the assumptions that production and pollution abatement are separable and actual production is efficient (Archibald (1988), Wossink et al. (2001), Wossink and Denaux Sogutlu (2002)). These assumptions imply that a firm can control its emission by either applying end-of-pipe measures or by reducing output. End-of-pipe measures are implemented after actual production and include the treatment of waste and safe environmental disposal (Hart (1995), Cagno et al. (2005), Hellweg et al. (2005)). Conventional theory considers emission as a fixed proportion of a firm's output (Xepapadeas, 1997). This strict joint production relation (Whitcomb, 1972) implies weak disposability for pollution. Weak disposability only allows for a proportional reduction of outputs and pollution (Shephard, 1970). Pollution control is then always costly (Wossink and Denaux Sogutlu (2002)). According to conventional theory, economy and environment have to be considered as substitutable – they are not complementary (Karvonen, 2001).

The conventional theory-based negative relationship between economic and environmental performance and the underlying assumptions becomes, however, more and more criticized. Wossink et al. (2001), for example, 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. Pollution most often result from specific inputs that have the characteristics of joint inputs, as any quantity simultaneously produces the intended output and the unintended pollution. The combination in which these marketable outputs and bad side effects is generated depends on the production method chosen – this combination is not fixed. This means that it becomes technically feasible to substitute inputs or introduce new production processes or inputs to reduce the level of the pollution without reducing the level of planned output.

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

Wossink and Denaux Sogutlu (2002) state that efficiency improvements can offset (part of) the costs associated with better environmental quality of production. De Koeijer et al. (1999) argue that using inputs more efficiently may lead to the achievement of both economic and environmental objectives simultaneously. This implies that pollution cannot always be considered as weakly disposable, meaning that environmental improvement does not necessarily need to come at a private cost.

Hill et al. (1999) distinguish three main stages in the process of firm level transition to environmentally sound production practices: (1) efficiency improvement, (2) substitution of inputs or production processes and (3) output reduction or the use of new or additive technology for environmental purposes.

Porter and van der Linde (1995) put forward a win-win hypothesis, arguing that improved environmental performance is a potential source for competitive advantage as it can lead to more efficient processes, improvements in productivity, lower costs of compliance and new market opportunities. Two reasons underpin this argument: first, firms facing higher pollution costs have an incentive to research new technologies and production approaches that can ultimately reduce the cost of compliance. Innovations also result in lower production costs, e.g. lower input costs due to enhanced productivity. Second, firms can gain 'first mover advantages' through selling new solutions and innovations to other firms (Esty and Porter, 1998). Researchers such as Hart (1995), Shrivastava (1995), Karagozoglu and Lindell (2000) and Aragon-Correa and Sharma (2003) construct a theoretical view for the win-win perspective, arguing that stringent environmental regulations lead to more competition and stimulate innovation and efficiency.

Concepts for measuring contributions to sustainability are also built on the win-win perspective. Eco-efficiency, for example, is based on creating more goods and services while using fewer resources and creating less waste and pollution (WBCSD, 2000). Sustainable Value Added (Figge and Hahn, 2004) measures whether a company creates more value while ensuring that every environmental (and social) impact remains in total constant.

The inverted U-shaped relationship between economic and environmental performance at micro level stems from the basic ideas behind the environmental Kuznets curve at macro level (Karvonen, 2001). Below a certain level of income, economic growth and environmental degradation are positively related where after the relationship turns negative (Grossman and Krueger (1991), World Bank (1992), Selden and Song (1994), Shafik (1994)). Economy and environment are then considered as complements or substitutes (Karvonen, 2001), depending on the level of environmental degradation.

Under the revisionist's hypothesis, reducing output and applying end-of-pipe measures are not the only possible management activities to improve environmental performance. Multiple authors (e.g. Rennings (2000), Sarkis and Cordeiro (2001), Beaumont and Tinch (2004), Wagner (2005), Claver et al. (2007), Frondel et al. (2008), Boons and Wagner (2009)) distinguish between integrated pollution prevention, directly addressing the cause of emissions, and additive end-of-pipe measures. Examples of pollution prevention are modifying production system's equipment and operations, using different raw materials, product redesign or reformulation and in-process recycling (Oldenburg (1987), Cagno et al. (2005)). Note that there is no complete agreement in literature on the positioning of the boundary between pollution prevention and end-of-pipe measures. On-site and off-site recycling of waste, for example, may be classified under both types of measures (Cagno et al., 2005).

The validity of the win-win hypothesis has been criticized as well. Walley and Whitehead (1994), for example, suggest that the cases of the win-win scenario are likely to be very limited in practice. Palmer et al. (1995) argue that little evidence is offered and more empirical analysis is necessary to establish the extent of the effect.

A large number of empirical studies assess the relationship between economic and environmental performance, but they have not been conclusive. Based on a meta-analysis, Orlitzky et al. (2003) conclude that there is still significant variation across individual studies, ranging from (few) negative to insignificant to moderately or even strongly positive links identified. Negative links are found in, for example, Jaggi and Freedman (1992), Sarkis and Cordeiro (2001) and Thornton et al. (2003), while positive links are found in Cormier et al. (1993), Hart and Ahuja (1996), Klassen and McLaughlin (1996), Sharma and Vredenburg (1998), Konar and Cohen (2001), Murty and Kumar (2003), Al-Tuwaijri et al. (2004), Garcia Rodriguez and Mar Armas Cruz (2007) and Mazzanti and Zoboli (2009).

Multiple reasons are put forward for the disparity in results between different empirical studies. Several authors (e.g. Konar and Cohen (2001), Wagner (2001), Elsayed and Paton (2005), Claver et al. (2007), Garcia Rodriguez and Mar Armas Cruz (2007), Boons and Wagner (2009)) argue that the use of different indicators to measure economic or environmental performance may lead to contradictory results. Economic performance is often assessed with accounting based measures, which may be strategically influenced by managers, or with stock market measures, which may reflect beliefs of stock traders about the value of a firm. Therefore, these measures may not correspond completely to the firm's economic performance. Similarly, environmental performance may differ, depending on emissions and resources included and the way they are aggregated (Boons and Wagner, 2009).

Some authors (e.g. McWilliams and Siegel (1997), Wagner (2001), Elsayed and Paton (2005), Claver et al. (2007)) argue that the applied method to find a link between economic and environmental performance may also influence results. Methods that are often used are event studies, (model) portfolio research and regression-based studies (Wagner, 2001). Results may also be contradictory because small samples are used (Cohen et al. (1997), Konar and Cohen (2001), Elsayed and Paton (2005)), different samples address different sectors or industries (Sarkis and Cordeiro (2001), Wagner (2001), Wagner (2005), Garcia Rodriguez and Mar Armas Cruz (2007)), effects are considered in the short term or in the long term (Rugman and Verbeke (1998), Garcia Rodriguez and Mar Armas Cruz (2007), Boons and Wagner (2009)) and models are not correctly specified because variables are omitted that have been shown to be important determinants of economic and/or environmental performance (Ullmann (1985), McWilliams and Siegel (2000), Claver et al. (2007)).

2.2. Necessary conditions for adequate trade-off analysis

Based on the disparity between empirical results, some authors make recommendations to be taken into account when assessing the linkage between economic and environmental performance. According to Boons and Wagner (2009), a central issue in looking at the relationship between economic and environmental performance is the definition of the system (e.g. individual firm, market, production and consumption systems, national economic systems) for which the relationship is assessed. Researchers often tend to be implicit about the way in which they define the system. However, the link between economic and environmental performance takes different shapes depending on the system that is considered.

Several authors (e.g. King and Lenox (2001), Sarkis and Cordeiro (2001), Wagner (2001), Wagner (2005), Boons and Wagner (2008)) express the need for a deeper understanding of the link between economic and environmental performance and the forces influencing the relationship. Wagner (2001) argues that resolving the correlation aspects between economic and environmental performance would still leave the question of the direction of causality between both performances. In order to assess this causality, Sarkis and Cordeiro (2001) and Wagner (2001) argue for distinguishing between different forces, since they may lead to different economic and environmental effects. Also Schaltegger and Synnestvedt (2002) state that not merely the environmental performance level, but mainly the kind of environmental management with which a given level is achieved, influences the economic outcome. The relation between economic and environmental performance depends on the kind of management activities, strategies and concepts and whether they are applied correctly in the right situation (i.e. there is a fit of the environmental management approach with the given situation). King and Lenox (2001) state that it may be that it pays to reduce pollution by some means but not by other.

When assessing the economy-environment relationship at firm level, it is important to take into account firm-specific differences (King and Lenox (2001), Schaltegger and Synnestvedt (2002), Elsayed and Paton (2005)). Better understanding of these differences may provide a richer understanding of profitable environmental improvements. It may be that only firms with certain attributes can profitably reduce their pollution.

Note that not only firm-specific differences should be taken into account. Wagner (2001) states that the relationship between economic and environmental performance also depends on the type and stringency of regulation and on the market structure.

In order to construct a framework for analyzing economic-environmental trade-offs, it is necessary to take into account the recommendations from literature. In summary, five conditions for trade-off analysis can be put forward:

1. Delimitation of a clear system for which trade-offs are analyzed;
2. Assessment of the direction of causality between economic performance and environmental pressure;
3. Taking into account firm-specific trade-off differences;
4. Comprehensiveness with respect to management activities that can be evaluated;
5. Flexibility to analyze trade-offs under a wide range of market and environmental regulation conditions.

The first condition is rather easy to comply with since a system delimitation is an *a priori* choice. In our case, the system is the firm. The second condition is more a concern since according to literature, causality links depend on the type of management activity that is applied. Section 3 presents a basis for analyzing causality by elaborating the linkage between production, economic performance and environmental performance. In section 4, the research question is then whether these production-theoretical foundations can be used for analyzing firm-specific (condition 3) economic-environmental implications of multiple management activities (condition 4) under different market and environmental regulation conditions (condition 5). The management activities that are evaluated include both pollution prevention and end-of-pipe measures. The following pollution prevention measures are distinguished: efficiency improvement, scale adaptation, input rearrangement, output rearrangement, introducing environmental friendly inputs and product differentiation. If all five conditions are fulfilled, a framework is established.

3. Linking production to economics and pollution

In order to assess the direction of causality between economic performance and environmental pressure, we start from production-theoretical foundations. The well-known D(river)P(ressure)S(tate)I(mpact)-R(esponse) causality concept (Smeets and Weterings, 1999) indicates a direct linkage between the activity of a firm (D) and environmental pressure (P). Since also economic performance is directly related to the activity of a firm, the exploration of economic-environmental trade-offs requires taking into account this driver, which commonly involves the transformation of input(s) into output(s). Moreover, various pollution prevention measures are related to the transformation of inputs into outputs.

Figure 1 presents a one input-one output production function that represents the production technology of a particular firm. The hill-shaped production function was initiated by Pareto (1906) and assumes increasing returns to variable input at low input levels and decreasing returns at high input levels. The considered firm uses X_f input to produce Y_f output. If input and output prices are known, cost and revenue functions that are consistent with the production function can be derived. In figure 1, the short run is considered. If perfect competition is assumed, marginal revenues equal output price and the firm operates where marginal costs equal marginal revenues. Profit is represented by the shaded area between the marginal revenue function and the average costs at the output level.

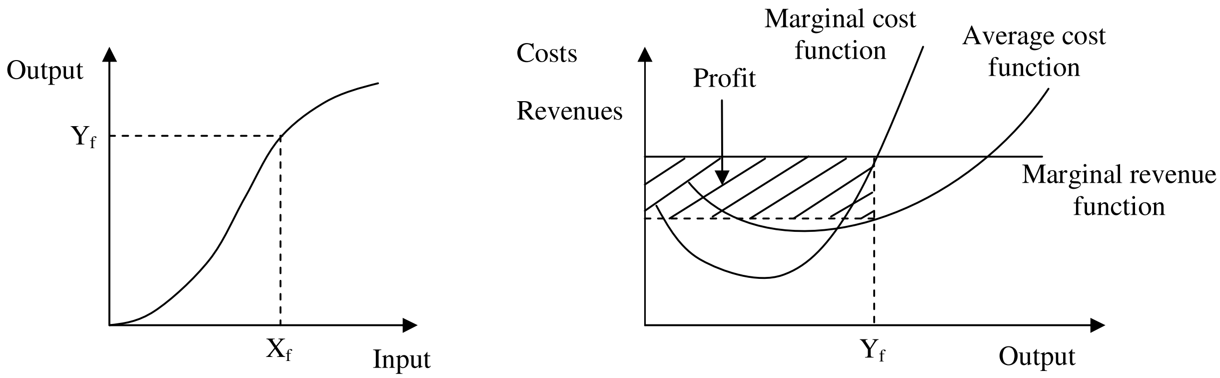

Figure 1 Production and profit under perfect competition in the short term

The question rises how to integrate environmental performance into 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), Lauwers (2009)) argue that some of these approaches are inconsistent with the materials balance condition.

The materials balance conditions implies that, 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). In this paper, we focus on types of pollution for which the materials balance principle applies. Note however that there are also pollution types for which the materials balance principle is not applicable (e.g. noise, visual pollution…).

Equation (1) calculates the amount of residual matter (pollution) by linking environmental coefficients to input(s) and output(s), in a similar way that economic performance is calculated by linking price coefficients to input(s) and output(s). We assume the balance variable to be a linear function of conventional input(s) and output(s).

(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)

Once the environmental 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 hill-shaped production function for the considered firm. Environmental performance is represented by the shaded area that adds up marginal pollution up to the output level of the firm.

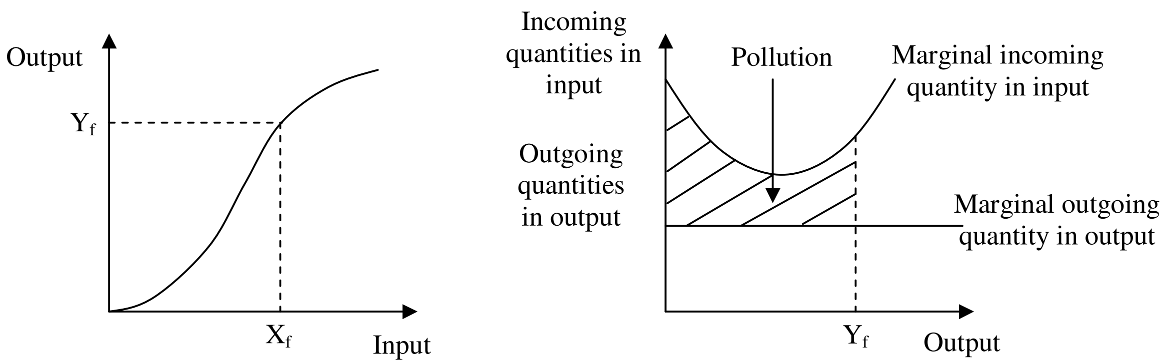

Figure 2 Production and materials balance based pollution

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) $$\frac{dR}{dX} > 0$$

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

(3) $$\frac{dR}{dY} > 0$$

Under the condition of a positive marginal product, marginal pollution is also positive. If output increases, pollution will also increase. In Section 4, this conclusion will be taken into account when assessing economic-environmental trade-offs implied by the distinguished measures.

4. Economic-environmental trade-off framework

In this section, the obtained production-theoretical insights are used to construct a framework for analyzing firm-specific economic-environmental implications of multiple management activities under different market and environmental regulation conditions. The framework integrates the five distinguished necessary conditions for trade-off analysis. Economic-environmental implications are assessed for both pollution prevention and end-of-pipe measures. For each measure, it is indicated under which market conditions the measure can be applied. Trade-offs are elaborated both in the presence and absence of environmental regulation costs. It is assumed that the adoption of the trade-off measures implies no transaction costs.

4.1. End-of-pipe measures

End-of-pipe measures aim at pollution abatement after pollution has already been generated. The adoption of such measures implies additional costs. However, applying end-of-pipe measures may also lead to less internalization costs for the firm. If the reduction in internalization costs is higher than the additional costs of adopting end-of-pipe measures, a positive economic-environmental trade-off is established. If the internalization costs do not diminish or the reduction is less than the additional costs of applying end-of-pipe measures, a negative trade-off is implied. End-of-pipe measures are applicable under both perfect and imperfect competitive market conditions.

4.2. Efficiency improvement and input or output rearrangement

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). Under constant returns to scale, input oriented technical efficiency equals output oriented technical efficiency.

Based on the study by Lauwers et al. (1999), Coelli et al. (2007) incorporate the materials balance concept for pollution into efficiency measurement. In a similar manner to the conventional cost efficiency decomposition, an environmental efficiency measure is defined that can be decomposed into technical and allocative components. Lauwers (2009) states that the decomposition into a technical and two allocative efficiency scores allows for an enhanced diagnostic power to analyze the trade-offs between minimizing costs and optimizing environmental performance.

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 and is derived from the production function. Given the input prices, there is a combination of inputs on each unit-isoquant that minimizes input costs. Similarly, given their environmental coefficients, there is an input combination that maximizes environmental efficiency. The cost efficient input combination is located where the proportion of input prices equals the marginal substitution rate of inputs. Similarly, the environmental efficient input combination is located where the proportion of environmental coefficients of inputs equals their marginal substitution rate.

The upper unit-isoquant represents the production technology of a firm that currently uses input quantities $X1_f$ and $X2_f$ to produce one unit of output. Substituting X1 by X2 (path 1) results in an input allocation that yields less input costs and a better environmental performance, and therefore implies a positive trade-off. The better environmental performance may even result in less internalization costs, strengthening the positive trade-off.

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

Beyond the input combination that minimizes input costs, further substitution of X1 by X2 (path 2) increases input costs but improves environmental performance. In the absence of internalization costs, a negative trade-off is established. If the firm is facing internalization costs, the improved environmental performance may result in less internalization costs. As long as the reduction in internalization costs is higher than the increase in input costs, further substituting X1 by X2 is economically profitable for the firm and a positive trade-off is established. If the reduction in internalization costs is lower than the increase in input costs, further substituting X1 by X2 implies a decrease in economic performance and a negative trade-off is established.

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, on the other hand, imply an altering production function.

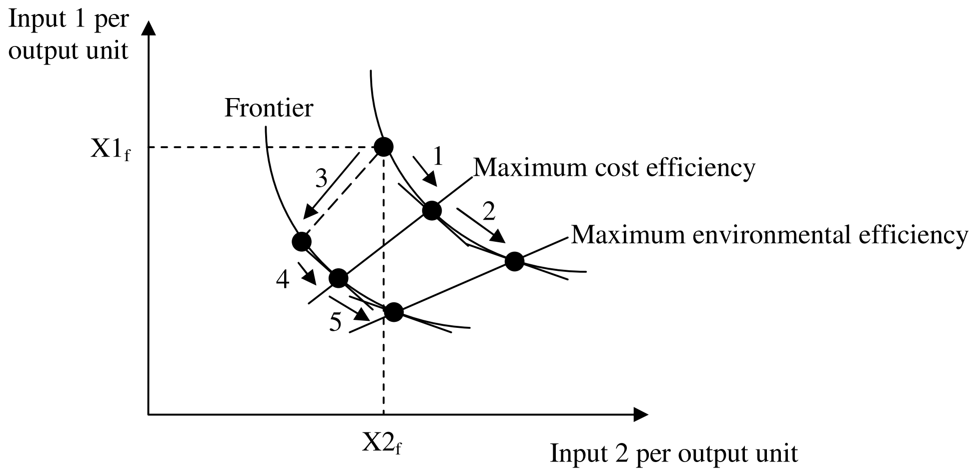

Figure 3 Trade-offs through efficiency improvement and input substitution

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 the management of the firm. If the firm improves its technical efficiency (path 3), input costs decrease and environmental performance improves, so a positive trade-off is established. The better environmental performance may even result in less internalization costs, strengthening the positive trade-off.

Once arrived on the frontier, the firm is able to further allocate inputs. Improvement paths 4 and 5 represent the substitution of inputs on the production frontier and imply similar trade-offs as those discussed under paths 1 and 2.

The example above describes the principles by which efficiency improvements and input rearrangements may yield positive or negative economic-environmental trade-offs. The direction of improvement paths towards optimal input allocations may, however, differ between firms. Different firms may use different input-output combinations and may have different production functions, prices and environmental coefficients. Consequently, optimal input allocations may also differ, making economic-environmental trade-offs through input substitution firm-dependent.

Figure 3 uses two parallel unit-isoquants. However, the adoption of a better management practice or a new production technology does not necessarily yield a unit-isoquant that is parallel to the original one. A different slope of the unit-isoquant influences optimal input combinations and therefore may also affect economic-environmental trade-offs through input substitution.

Note that firms adopting a better management practice or a new production technology mostly do not follow improvement paths that are mere technical or allocative efficiency improvements. In practice, improvement paths are mostly combinations of technical and allocative efficiency improvements.

The example above is worked out in an input-input space, allowing for input-oriented technical efficiency improvements and input mix allocative efficiency improvements. In the case of multiple outputs, firms may also improve output mix allocative efficiencies. In the case of two outputs with their own prices and environmental coefficients, a figure similar to figure 3 can be constructed in an output-output space using production possibility curves. Economic-environmental trade-offs established through output-oriented technical efficiency improvements and output rearrangements can then be analyzed in a similar way as trade-offs are analyzed in input-input space.

Note that technical efficiency improvements and input-rearrangements are only possible under perfect competition in the short term and under imperfect competition. Perfect competition in the long term implies that firms are fully cost efficient, operating at minimal average costs. Since no economic profit is made under perfect competition in the long run, firms that are not cost efficient will leave the market.

4.3. Scale adaptation

In the middle run, firms may adapt their economic scale. In this section, economic-environmental implications of adapting economic scale are elaborated for the case of perfect competition. Similar trade-offs occur under imperfect competition.

Under perfect competition, optimal economic scale implies that long term marginal costs equal long term marginal revenues and average costs. Above optimal economic scale, marginal costs for producing one unit of output more exceed marginal revenues. Below optimal economic scale, marginal costs are lower than marginal revenues. Figure 4 shows for a firm its optimal economic scale, which lies at output level Y_s.

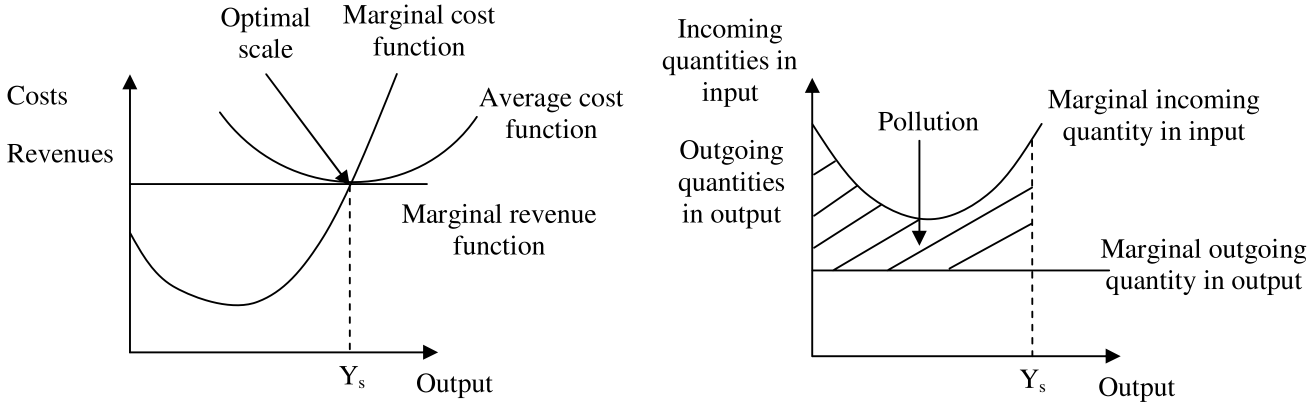

Figure 4 Trade-offs through scale adaptation

First, suppose that the firm produces less than Y_s output. In that case, economic scale can be optimized by increasing the output level. However, more output implies that pollution also increases, since marginal pollution is always positive. In the absence of internalization costs, exploiting economies of scale through increasing output implies a negative economic-environmental trade-off. If the firm is facing internalization costs, the diminished environmental performance may result in more internalization costs. As long as the economic gains through scale increase are higher than the increase in internalization costs, overall economic performance improves while environmental performance diminishes. If the increased internalization costs are not compensated by the economic gains through scale increase, both overall economic and environmental performance will decrease.

Second, suppose that the firm produces more than Y_s output. Now, economic performance can be increased by decreasing the output level. A lower output level implies less pollution and may also result in less internalization costs. Therefore, decreasing scale towards optimal scale implies a positive economic-environmental trade-off. Note that further decreasing output below optimal scale may also yield a positive trade-off. This is the case when the economic loss through scale decrease is more than compensated by the decrease in internalization costs.

Summarizing, a decrease in output through scale reduction may improve simultaneously economic and environmental performance. This is not in line with conventional theory, where output reduction is also considered to improve environmental performance, but where output reduction is assumed to imply a lower economic performance (see section 2).

4.4. Using less costly or environmental friendly inputs

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

If a firm, for example, uses the same inputs but purchases them at lower prices, price proportions and consequently, cost minimizing input combinations, might be the same, but nevertheless, economic performance is better because costs are lower. Buying the same inputs at lower prices therefore improves economic performance, without affecting environmental performance. Note that input and output prices can only be firm-dependent under imperfect competition. Perfect competition implies that farmers are price-takers.

Similarly, if a firm uses the same inputs, but with lower environmental coefficients, its environmental performance improves. In the absence of internalization costs, economic performance does not change. If the firm is facing internalization costs, the improved environmental performance may result in less internalization costs, implying a positive trade-off.

Figure 5 illustrates the effect of using environmental friendly inputs on environmental performance for a firm that produces an amount Y_f. If environmental friendly inputs are used, the function representing incoming quantity in input will shift downward and pollution (difference between incoming and outgoing quantity) will diminish. Note that the slope of the incoming quantity function is always steeper than the slope of the outgoing quantity function. This is because marginal pollution is always positive.

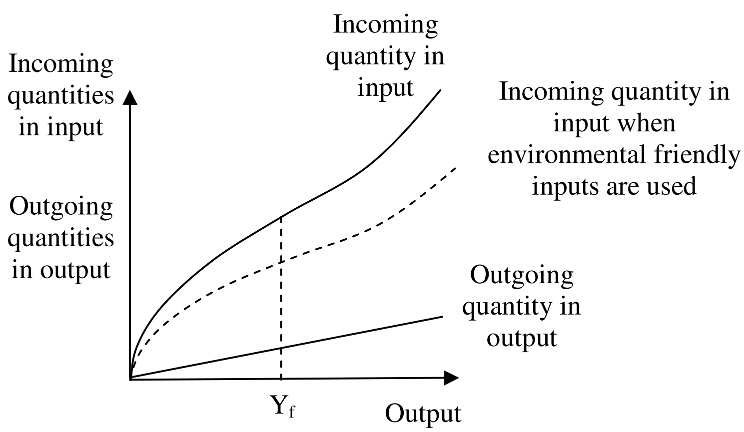

Figure 5 Effect of using environmental friendly inputs on environmental performance

4.5. Product differentiation

Product differentiation is only possible under imperfect competition, since perfect competition assumes homogeneous products. Firms may choose for product differentiation to improve product quality and 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 environmental performance. If more, other or additional inputs are used for improving output quality, this corresponds to the adoption of a new technology. Consequently, the production function, prices and environmental coefficients may change and both economic and environmental performance may be affected.

5. Conclusion

This paper provides a framework for analyzing trade-offs between economic performance and environmental pressure at firm level. The framework integrates five necessary conditions for economic-environmental trade-off analysis. These conditions are put forward based on recommendations from literature. Discrepancies between existing empirical studies are mainly caused by the fact that these conditions are not taken into account.

The five necessary conditions are: delimitating a clear system for which trade-offs are analyzed, assessing the direction of causality between economic performance and environmental pressure, allowing for firm-specific trade-off differences, comprehensiveness with respect to management activities that can be evaluated and flexibility to analyze trade-offs under different market and environmental regulation conditions.

System delimitation is rather easy in our case: we consider the firm as the system. To deal with the causality condition, theoretically consistent production, cost, revenue and emission functions are constructed, taking into account the materials balance principle for emission. The linkage between production, economic performance and environmental pressure is then used to construct a framework that integrates the five necessary conditions.

Our theoretical elaboration shows that both pollution prevention and end-of-pipe measures may yield positive or negative economic-environmental trade-offs. Economic-environmental implications are firm-specific and depend on the management activity that is applied, on the market conditions and on environmental regulation conditions. Economic-environmental implications different management activities represent in fact different stages in the trade-off curve. The partially conflicting trade-off paradigms in literature can also be considered as different stages in the trade-off curve.

Although a firm-specific trade-off curve gives a clear view on the measures that are economically to be preferred to reduce environmental pressure, this does does not guarantee that the firm will actually adopt these measures. Several studies elaborate on the factors that may influence the adoption of measures influencing economic and environmental performance. These factors include the presence of investment barriers like the availability of resources and payback time (Karvonen, 2001), risks involved with the adoption (Rugman and Verbeke, 1998), knowledge spillover effects (Mazzanti and Zoboli (2005), Galdeano-Gomez and Cespedes-Lorente (2008), Galdeano-Gomez et al. (2008)), satisfying objectives instead of profit maximizing behavior (Boons and Wagner, 2009), environmental regulation (Pickman, 1998) and the design (Majumdar and Marcus, 2001) and stringency of environmental regulation (Mazzanti and Zoboli (2005), Frondel et al. (2008)).

The question now rises how to make the production-theoretical framework operational. Suitable methods should be able to identify firm-specific economic-environmental improvement paths and simulate the effect of different improvement measures on economic performance and environmental pressure. The established framework shows the importance of the notion of the production function of the firm, together with the production frontier. Frontier-based methods therefore seem indispensable when analyzing economic-environmental trade-offs. Suitable methods must also allow for dealing with the materials balance principle. Based on the work by Lauwers et al. (1999), Coelli et al. (2007) incorporate the materials balance concept for pollution into frontier analysis.

Lauwers (2009) further elaborates on the justification of incorporating the materials balance principle into frontier-based models and discusses potentialities and bottlenecks. While firm-specific trade-off analysis is mentioned as an important potentiality, possible bottlenecks include generalization to multiple environmental issues and to immaterial external effects (such as noise, visual pollution), availability of the per unit input or output emission coefficients, system delimitation and non-linearity with environmental pressure. As Lauwers (2009) concludes, these bottlenecks provide a range of starting points for further research.

In this paper, the materials balance principle is used assess pollution as residual matter. Note however that some types of residual matter may also imply positive environmental effects. In that case, a similar production-theoretical framework can be constructed, but the implied trade-offs differ since maximization of positive environmental effects is required instead of minimization of pollution.

Further research may also focus on the choice of most suitable frontier method to be used for applying the production-theoretical framework for trade-off analysis. Another research question is whether frontier methods as such are sufficient to make the framework operational. It is not clear whether they allow for assessing all of the distinguished trade-off measures. In addition, for communication purposes, it may be appropriate to use frontier methods in combination with performance indicators that are more commonly used in practice, since firms are mostly not familiar with frontier concepts and efficiency scores.

Overall, we can conclude that this paper provides a new production-theoretical framework to support firms with their decisions on improving economic performance and reducing environmental pressure. The framework may also help policy makers to identify policy options to reduce environmental pressure without negatively affecting economic performance of firms.

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