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Multiprogram Interaction between Mitigation and Adaptation Programs: Optimization Opportunity for Governments Addressing Climate Change

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Abstract

This article addresses the concepts of economies of scope and multiprogram production, subadditivity and transray convexity as it applies to program optimization. The article goes on to expand these concepts to include the special case of climate change. As mitigation and adaptation programs addressing climate change are considered public goods and thus fall under the purview of governments, it discusses how the modification of climate change programs can develop a relationship across the cost functions of the modified mitigation and adaptation program production and consequently how this interrelationship affects the net benefit maximizing conditions.

Keywords: Mitigation; Adaptation; Climate Change

Introduction

The question of how to approach climate change is a complex issue. It is our belief that the solution does not reside in mitigation or adaptation programs in isolation, but in the optimal combination of both [1]. Numerous papers have been published covering mitigation approaches and programmes [2-5] as well as adaptation approaches and programmes [6-8] but inadequate research has been conducted on the combination of the two occurring simultaneously. This paper serves to partially fill this gap.

In general, consideration is given to either a mitigation strategy or an adaptation one. In the special case of climate change, the planning and implementation of mitigation and adaptation policies and programmes currently faces many challenges, not least of which is cost-based and also potential social impacts. It is, as is the position in the general case, incorrectly perceived that mitigation and adaptation programmes are mutually exclusive, leading to a need to bring the two approaches together and to thereafter be optimised.

Programs may contain more than one economically viable resource, so it makes sense to develop all the resources at the same time rather than build separate facilities to cope with each resource. It is less expensive to do this. This occurs because of economies of scope, or more specifically due to the typical subadditivity in the firm's aggregate cost function [9]. There are four reasons why this occurs:

1. The company has an institutional structure in place capable of, and experienced in dealing with the output;
2. The company already has in place a staff of engineers familiar with the processes and characteristics;
3. The company has a management staff well-versed in the benefits and principles of cost minimization; and
4. The company has capital infrastructure in place (e.g. place of business, computers, etc.) and does not need to recreate or duplicate it.

Therefore, owing to shared and proportionally lower expenses of already-in-place assets and personnel, the company is capable of providing multiple products at a cost equal to or less than the cost it would incur if it had to construct two or more separate facilities. An interesting development occurs when the special case of climate change is considered.

As can be expected, certain limitations exist in the methodology discussed in this paper. These limitations can be grouped together and provide an opportunity for further consideration. Specifically, the limitations herein relate to the fact that not all circumstances within the climate change space can be addressed through a combined mitigation and adaptation programme and may still be responsive to only one or the other strategies.

Background - The General Case

Within a multiproduct space, we let the prices for output be determined in the market and assume that the firms or operations do not have sufficient market power to influence the price. To these firms this means that the output price is exogenously determined and independent of the firms' actions. This gives rise to a multiproduct revenue plane. If we assume that the multiproduct output firm is a mining operation, then in a broad manner, waste and ore are two products, the latter from which revenue will be derived dependent on that ore's economic metals content. Many mining operations exploit orebodies that host more than one mineral and hence they extract multiple saleable products from the same ore. An example of a revenue hyperplane is shown in Figure 1.

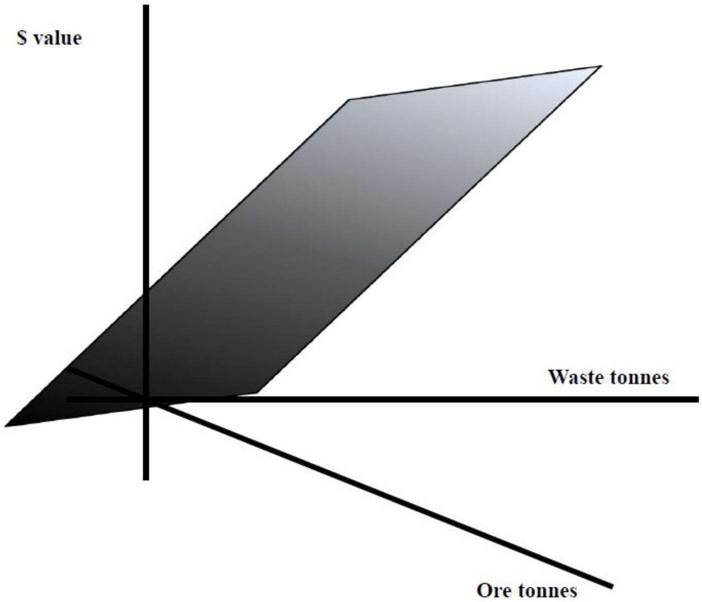

Figure 1: Revenue Hyperplane Curve

Simplistically, this means that multiple firms' or mining operations' control variables lie within the realm of their cost structures, singularly and collectively. For a particular multiproduct revenue plane, a firm or operation has the incentive to choose the cost functions that corresponds with the different products and, given a set of fixed prices, the firm has the incentive to choose Ramsey-optimal cost output vectors[1]. This is the optimal mix of products that will satisfy the existing demand for output from the firm or operation [10].

As the cost functions for the different processes are similar within the total cost function, the transition[2] from one subset of costs to another is smoothed and the individual cost functions can be aggregated into one generalized form[3]. Then, for some positive output ($y^a > 0$), the aggregated cost function [$C_1(y^a)$] is determined by (and composed of) a combination of the costs associated with the individual production processes (c_{1i}, i=1, 2 ….., n). While it is extremely difficult to describe the exact average costs for the operation providing the multiproduct output, it is possible to describe how costs relate to this output as the output increases proportionately (i.e. ray average cost or RAC).

For two levels of output (k and v where v > k) having a ray through some output of good (y^a), a ray average cost can be defined as $RAC = C(ky^a)/k$. This implies that the RAC along a ray through y^a is strictly declining if $C(ky^a)/k > C(vy^a)/v > k^4$. Since multiproduct production is being addressed, it is necessary to construct another analogous cost function for the firm or operation's output of the second good or mineral (y^b) with an associated aggregated cost function [$C_2(y^b)$] determined by (and composed of) combinations of costs associated with the individual goods' or minerals' production processes (c_{2j}, j=1, 2 …..,m). Thus for the case of two goods or saleable minerals, the total aggregated cost function is equal to the sum of the two production costs. That is $[C(y)] = [C_1(y^a)] + C_2(y^b)]$.

[1] $P_i^* - MC_i = -\lambda(MR_i - MC_i)$ $for\ y_i^* > 0$

$P_i^* - MC_i \leq -\lambda(MR_i - MC_i)$ $for\ y_i^* > 0$

With $\lambda \geq 0$ where * indicates optimal values and p_i, y_i, MC_i and MR_i are the prices, quantities, marginal costs and marginal revenues for the mines actual and potential products N. All Ramsey-optimal price-output vectors satisfy the above by Kuhn-Tucker Theorem.

[2]For example, the transition would be smoothed when the process for changing from the production of one output to another occurred when there was a need to change reagents. Thus, the cost would be reduced as the production process was going to be halted anyway.

[3]Aggregated cost functions have in the past been used to estimate technical change and scale economies. L.R. Christensen, D.W. Jorgenstern and L.J. Lau, 'Conjugate duality and transcendental logarithmic modification function', Econometrica, Vol. 39, 1971, pp 255-256.

A cost function is said to be subadditive if, with given input prices, one firm or operation can produce a given output vector, y*, more cheaply than the same output can be produced by any combination of two or more firms or operations, each having the same cost function, C(y). More formally, any C(y) is subadditive at the output vector y* if for all sets of output vectors y^i (i = a, b,….) such that $\Sigma y^i = y^*$, $\sum C(y^1) > \sum C(y^*)$ [11,12]. The subadditivity of the firm or operation's joint aggregate cost function is such that the multi-dimensional transray convexity exists over the relevant range of the cost surface [13] where transray convexity is defined as follows. If at a point in output space, y, there exists at least one negatively sloping (transray) cross-section such that the costs are not higher towards the edges, then the cost function C(y) is trans ray convex at y. More formally, a cost function, C(y), is transray convex at y if a set of input prices exists as $w_1 \ldots w_n$, such that for every two output vectors, $y^a = \left(y_1^a, \ldots . y_n^q\right)$ and $y^b = \left(y_1^b, \ldots ., y_m^b\right)$, satisfying $\sum w_i y_i^a = \sum w_i y_i^a = \sum w_i y_j^b = \sum w_1 y_1$, gives rise to $C\ [ky^a + (1-k)\, y^b] \le kC\ (y^a) + (1-k)\ C\ (y^b)$ [14]. An example of a RAC isocost surface displaying transray convexity is shown in Figure 2.

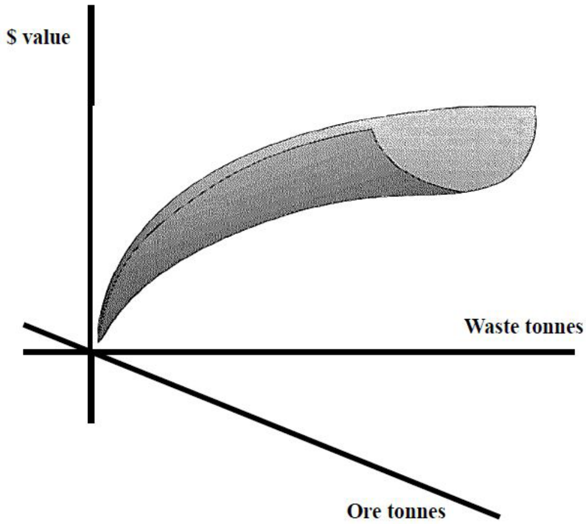

Figure 2: Isocost Surface

The firm or operation has the profit incentive to choose the least cost combination of output (as prices are market determined and viewed as given by the producer). Let an operation producing two outputs (minerals), y_1 and y_2, have a generalized revenue function R with prices p_1 and p_2, such that $R = R(p_1, p_2, y_1, y_2)$ and $R = p_1 y_1 + p_2 y_2$. The generalized cost function, C, is $C = C_i\ (y_1, y_2)$ and C = $C = C_1(y_1) + C_2(y_2)$. Letting R_1 be the revenue associated with the sale of product 1 and R_2 be the revenue associated with the sale of product 2, the generalized profit function becomes $\pi = R_1(y_1+y_2) + R_2(y_1+y_2) - C_1(y_1) + C_2(y_2)$. Thus, the first order conditions are:

$\partial\pi / \partial y_1 = \partial R_1(y_1+y_2)/\partial y_1 + \partial R_2(y_1+y_2)/\partial y_1 - \partial C_1(y_1)/\partial y_1 = 0$ and

$\partial\pi / \partial y_2 = \partial R_1(y_1+y_2)/\partial y_2 + \partial R_2(y_1+y_2)/\partial y_2 - \partial C_2(y_2)/\partial y_2 = 0$

Letting the product or minerals prices and sales be independent[4] results in $MR_1 = MC_1$ and $MR_2 = MC_2$[5]. That is, the profit maximizing case exists where the marginal revenues equal the marginal costs in each case (assuming second order conditions are met) [14].

Subadditivity and transray convexity are relevant for multiproduct output production where markets exist and prices are adequate for market participation. That is, the nature of the convexity suggests that the operation will be able to produce the two goods or minerals at a lower total cost than two operations producing the two products separately. Thus, the operation has an opportunity for increased profits, ceteris paribus [15].

Climate Change - Special Case

Moving from the general case involving multiproduct subadditivity to the production of multiple programs involving climate change, the situation is modified slightly, but with significant impacts. Mitigation and adaptation programs addressing climate change are considered to produce public goods. As such, they fall under the purview of governments. So instead of maximizing profits, as is the normal case for a private firm or mining operation, the goal is to maximize the net social benefit, where the latter is defined to be the sum of the total social benefit minus the total social costs. By design, mitigation programs are designed to remove carbon dioxide (CO_2) from the atmosphere, thereby reducing the climate change influencing effect of increased levels of CO_2 in the atmosphere. Alternatively, adaptation programs accept climate change as given and move to physically address the end product or output consequence (e.g. increase the height of an existing sea wall to address increasing sea levels) [16].

[4] $\partial\pi / \partial y_1 = \partial R_2(y_1+y_2)/\partial y_1 = 0$ and $\partial\pi/\partial y_2 = \partial R_1(y_1+y_2)/\partial y_2 = 0$

[5] For example, the demand for this firm's product is not influenced by the demand for a similar but alternative product.

Let the number of mitigation programs be significant to the extent that current production of those mitigation programs can be carried on for an extended period of time without fear of exhausting the existing programs. Also assume that when mitigation programs are employed, CO_2 is removed from site in sufficient quantities to reduce its climate changing impact. As a result, the costs associated with the implementation of an adaptation program that addresses the changing climate will likely decline. This means that the incorporation of one program (mitigation) can reduce the costs associated with the other (adaptation). Thus, in this case, the costs of mitigation are independent of adaptation, but the costs of adaptation are related to (can be reduced by) mitigation. This is a unidirectional dependency.

Let subscript a indicate variables related to adaptation and *m* indicate variables associated with mitigation, while other variables are defined as above. For a government conducting two programs producing two outputs, y_a (adaptation) and y_m (mitigation reducing CO_2), having a benefit function $B = B(p_a, p_m, y_a, y_m)$ and $B = p_a y_a + p_m y_m$ and a cost function $C = C_i (y_a, y_m)$ and $C = C(y_a) + C(y_m)$. The generalized net benefit function will be

$$\pi = B_a(y_a + y_m) + B_m(y_a + y_m) - C_a(y_a) - C_m(y_m).$$

Thus, the first order conditions are:

$$\partial\pi / \partial y_a = \partial B_a(y_a + y_m)/\partial y_a + \partial B_m(y_a + y_m)/\partial y_a - \partial C_a(y_a)/\partial y_a + \partial C_a(y_a)/\partial y_m = 0 \text{ and}$$

$$\partial\pi / \partial y_m = \partial B_a(y_a + y_m)/\partial y_m + \partial B_m(y_a + y_m)/\partial y_m - \partial C_m(y_m)/\partial y_m - \partial C_m(y_m)/\partial y_m = 0$$

The benefit maximizing position for mitigation is the same as that for y_2 above, but the benefit maximizing position for adaptation changes is unique. Letting the product benefit and execution of the two programs be independent results in the above first order condition and yields the following result for the benefit maximizing production of adaptation programs:

$$\partial\pi / \partial y_a = \partial B_a(y_a + y_m)/\partial y_a + \partial C_a(y_a)/\partial y_m - \partial C_a(y_a)/\partial y_m - \partial C_a(y_a)/\partial y_a = 0$$

In other words, the first order condition for benefit maximization occurs where the marginal benefit plus the reduction in costs due to mitigation, minus the marginal costs of executing the adaptation programs equals zero.

Implications

Turning the attention in this paper to look at potential implications of the benefit maximizing conditions, the following is considered. The first situation is the rejection scenario. If the costs of mitigation are high, or if the benefits of reducing the amount of CO_2 are low, then the benefits associated with multiprogram optimization may not meet the government's rate of return criteria, and the project will be rejected or discontinued. This situation could occur when the mitigation programs are difficult to sufficiently process to create a sustainable reduction in CO_2, making the benefits of reducing CO_2 minimal. In these cases, the government will not engage in developing multiple programs that use mitigation strategies, while its production of adaptation programs will remain unchanged.

The second situation is the market based scenario. In this case, mitigation strategies have a marketable product with a positive benefit and there is a significant benefit to the reduction in CO_2 (e.g. a reduction in CO_2 leads to a reduction in adaptation costs and creates a reduced but still negative climate change situation). If equal to (or greater than) normal benefits are being made from the execution of the mitigation programs alone, then the government should engage in the implementation of multiple programs. Moreover, a case can be made and supported for a multiprogram execution even if a loss is made from the mitigation strategy, provided that the decreases in costs of adaptation are greater than the costs associated with mitigation. In this case the overall net benefits of the government's action are positive and the multiple programs would be continued.

Finally, multiprogram benefits (mitigation and adaptation) can lead to increased incorporation of adaptation programs. If the law of diminishing marginal returns applies and duality is applicable, then as the number of programs increases so does the marginal

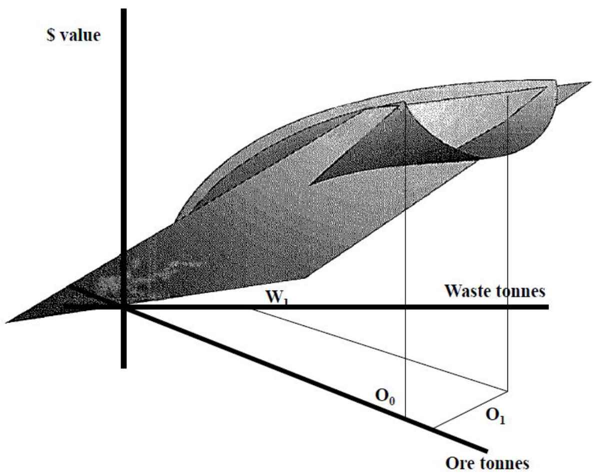

Figure 3: Single vs. Multiprogram Impacts

cost. As marginal benefits plus the decrease in the costs of adaptation programs is greater than the marginal benefits alone, and the benefit maximizing output is indicated where marginal benefits plus the decrease in the costs of adaptation programs equals the marginal costs of adaptation programs, then the marginal cost of adaptation is greater under the multiproduct regime. As we have not changed the production or cost functions of adaptation programs, the marginal cost of adaptation only increases if the benefits of adaptation are greater. Thus, assuming the above holds, the introduction of multiprogram production could lead to an increase in the production of adaptation in addition to the production of mitigation programs. Thus, the net result of multiprogram production would be a reduction of CO_2 through mitigation programs and an increase in the number of adaptation programs implemented. In a mining operation case moving ore (O) and waste (W), this is illustrated in Figure 3 where the level of adaptation increases from O_0 to O_1 as the number of mitigation programs goes from 0 to W_1 [17,18].

Summary

This article addressed the concepts of economies of scope and multiproduct production, subadditivity and transray convexity as they apply to industry (including mining), and then expanded these concepts to include the special case of Climate Change program optimization. It developed a mathematical illustration of how the modification of mitigation strategies develop a relationship across the cost functions of the modified mitigation and adaptation programs and how this interrelationship could affect the net benefit maximizing condition. It discusses three possible outcomes from mitigation and its effect on the adoption of adaptation programs by government for an economy resulting from the adoption of multiprograms utilizing subadditivity and transray convexity of production.

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