CENTRE OF PLANNING AND ECONOMIC RESEARCH

No 19
Ordering Equilibria by Output or Technology in a Non-linear Pricing Context

by

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February 1993

DISCUSSION PAPERS

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CENTRE OF PLANNING AND ECONOMIC RESEARCH

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ABSTRACT

This paper considers three types of piece-wise linear budget sets namely: nonconvex, discontinuous and convex, in a production context. We characterize cost minimizing input demand and cost functions and investigate the conditions under which equilibria may be ordered by technology and by output level. The analysis is extented to cover a situation involving *n* price regimes and empirical implications are discussed.

1. INTRODUCTION

Traditional demand analysis in both the producer and consumer context has been based on the assumption of linear pricing. One could, however, point to numerous empirical situations involving non-linear pricing and therefore non-linear budget sets. The most typical examples relate to labour supply under progressive taxation and to electricity demand in the face of piece-wise linear price schedules.

Existing literature on non-linear pricing originates in the work of Burtless and Hausman (1978) and Wales and Woodland (1979) on labour supply with taxes. These two papers represent also the two estimating approaches employed in the literature. The Hausman framework is based on the assumption of variable coefficient. Variation in preferences is exploited to associate each segment of the budget constraint with a subset of the parameter space. The likelihood function for a given sample of observations is then formed and maximised. Wales and Woodland search for the optimizing bundle for every individual in the sample, by checking each segment of the budget constraint. A least squares criterion is then applied to obtain estimates of the parameter vector. More recent empirical work in this area includes Hausman (1981), Zabalza (1983), Blomquist (1983) and Balfoussias (1990) on labour supply with taxes, Hausman (1980)] on housing demand and Balfoussias (1985) on electricity demand.

By and large the above studies are motivated by the need to design appropriate estimating techniques for particular empirical situations and do not provide a systematic discussion of the various issues relating to optimising behaviour under non-linear pricing. Furthermore the generality and robustness of certain estimating techniques is seldom discussed. Hausman's econometric construct, for example, is often assumed to be readily applicable in any multisegment budget constraint context.

This paper intends to contribute towards a clearer and more complete understanding of economic behaviour in the presence of non-linear pricing, with a view to enhance the scope for empirical investigation. The paper explores the question of ordering possible equilibria by personal characteristics, in a production context and for the case of three types of price schedules.

Optimizing behaviour in the presence of piece-wise linear pricing leads to non-analytical cost and demand functions for the individual. Full characterization of behaviour, however, calls for investigation of the conditions under which equilibrium relates to a given price regime. Moreover, once economic behaviour is classified, methods of econometric estimation are enriched and often facilitated considerably.

The paper is organised as follows. In section 2 we investigates the conditions under which price regimes can be ordered by output level in a two block context. In section 3 the question of ordering of regimes by output is examined under the assumption of n price regimes. Section 4 is about ordering of regimes by technology. Section 5 discusses the usefulness of the results and section 6 concludes.

2. ORDERING EQUILIBRIA BY OUTPUT LEVEL IN THE TWO-BLOCK CASE

The question to be examined in this section is the following:

Can individual behaviourbe systematically classified in such a way so as to associate any given individual with a certain price regime according to some measure of his personal characteristics?

Before addressing this question let us first characterise equilibrium under certain types of piece-wise linear pricing schedules.

2.1. Cost minimisation under piece-wise linear pricing

(i) A non-convexbudget set

Let the production function take the form $y = f(x_1, x_2, \theta)$, where y stands for a single output, x_1 and x_2 represent two factors of production and θ stands for a vector of technological parameters. It is assumed that x_2 can be purchased in unlimited quantities at p_2, whereas x_1 is purchased according to a two-part tariff. In particular let $\bar{x}_1$ stand for the fixed number of units in the primary block. Then the consumer's tariff consists of: (a) a unit charge, p_1, for each of the first $\bar{x}_1$ units and (b) a lower unit charge $p'_1 < p_1$, for each unit demanded in excess of $\bar{x}_1$. The effect of the piece-wise linearity in prices is to create a non-convex budget set. The cost minimizing decisions of individual producers are described by the expression:

$$\min\{\ C_0 = c(p_1, x_1, \bar{x}_1) + c'(p'_1, x_1, \bar{x}_1) + p_2 x_2 \ \mid\ y = f(x_1, x_2, \theta)\} \tag{1}$$

where $c(p_1, x_1, \bar{x}_1) = \begin{cases} p_1 x_1 & \text{if } x_1 \le \bar{x}_1 \\ p_1 \bar{x}_1 & \text{if } x_1 > \bar{x}_1 \end{cases}$ and $c'(p'_1, x_1, \bar{x}_1) = \begin{cases} 0 & \text{if } x_1 \le \bar{x}_1 \\ p'_1(x_1 - \bar{x}_1) & \text{if } x_1 > \bar{x}_1 \end{cases}$

The optimisation process is in effect divided into three parts: (a) minimize cost for $x_1 \le \bar{x}_1$, (b) minimize cost for $x_1 > \bar{x}_1$ and (c) compare local optima to obtain the global optimum.

Under the constraint $x_1 \le \bar{x}_1$ the Lagrangian function takes the form

$$Z = p_1 x_1 + p_2 x_2 + \lambda(y - f(x_1, x_2, \theta) + \mu(x_1 - \bar{x}_1)) \ . \tag{2}$$

The Kuhn-Tucker conditions for minimum are:

$$\partial Z/\partial x_1 = 0, \quad \partial Z/\partial x_2 = 0, \quad \partial Z/\partial \lambda = 0, \quad \partial Z/\partial \mu \le 0, \quad \mu \partial Z/\partial \mu = 0 \tag{3}$$

and the resulting cost function is given by

$$C = g(p_1, p_2, y, \theta) \quad \text{or} \quad C = h(p_1, p_2, y, \bar{x}_1, \theta) \tag{4}$$

where $g(.)$ is a cost function with conventional properties and $h(.)$ takes the form

$$h(p_1, p_2, y, \bar{x}_1 \theta) = p_1 \bar{x}_1 \ + \ p_2 x_2(y, \bar{x}_1, \theta) \ . \tag{5}$$

Under the constraint $x_1 > \bar{x}_1$ the Lagrangian function becomes

$$Z = \bar{x}_1(p_1 - p_1') + p_1' x_1 + p_2 x_2 + \lambda(y - f(x_1, x_2, \theta) + \mu(x_1 - \bar{x}_1)) \quad . \tag{6}$$

The Kuhn-Tucker conditions for minimum are:

$$\partial Z/\partial x_1 = 0, \quad \partial Z/\partial x_2 = 0, \quad \partial Z/\partial \lambda = 0, \quad \partial Z/\partial \mu = 0 \tag{7}$$

and the resulting cost function is given by:

$$C' = g'(p_1, p_1', p_2, y, \theta, \bar{x}_1)$$
$$C' = g(p_1', p_2, y, \theta) + \bar{x}_1(p_1 - p_1') \tag{8}$$

where $g(.)$ has the usual properties.

The global cost function minimum is defined by $Cg = \min\{C;C'\}$

$$Cg = \min\{[g(p_1, p_2, y, \theta) \text{ or } h(p_1, p_2, y, \bar{x}_1, \theta)] \;\; ; \;\; g'(p_1, p_1', p_2, y, \theta, \bar{x}_1)\} \quad . \tag{9}$$

Expression (9) describes the possible outcomes of cost minimisation in terms of cost functions for a two-segment, non-convex budget set. The following propositions can be stated regarding the functions representing local optima in (9).

***Proposition* 1.** *For any given set of values of the parameters* $p_1, p_2, p_1', y, \theta, \bar{x}_1$ *either* $g(.)$ *or* $g'(.)$ *or both exist.*

***Proposition* 2.** *By convexity and monotonicity of the production function* $g(.) < h(.)$ and $g' < h(.)$ *therefore* $\bar{x}_1$ *cannot represent the globally optimal choice. As a result equation (9) can be reduced to*

$$C_g = \min\{g(p_1, p_2, y, \theta);[(p_1', p_2, y, \theta) + \bar{x}_1(p_1 - p_1')]\} \quad . \tag{10}$$

Input demand functions are discontinuous and non differentiable for a small area around $\bar{x}_1$. They may also be multivalued, at certain configurations of prices and output, since a situation of multiple equilibria arises from (10). The overall cost and profit functions will however be continuous, exhibiting the usual comparative static properties as far as the first order derivatives are concerned.

(ii) A discontinuous budget set

A discontinuous budget set is generated by the following two-block price system on x_1. Any $x_1 < \bar{x}_1$ is purchased at a unit price p_1, but when $x_1 \geq \bar{x}_1$ the entire amount is priced at a lower unit price p_1'. The cost function associated with global optimum is given by

$$Cg = \min\{g(p_1, p_2, y, \theta); \;\; g'(p_1, p_1', p_2, y, \theta, \bar{x}_1) \text{ or } h'(p_1', p_1, p_2, y, \bar{x}_1, \theta) \;\; \} \quad . \tag{11}$$

Obviously proposition 1 holds for equation (11) as well. In addition the following propositions hold in relation to (11).

***Proposition* 3.** *If* $g'(.)$ *exists then* $Cg = g'(.)$.

This proposition follows directly from the assumed regularity of the functions $g(.)$ and $g'(.)$ and the form of the budget constraint. As a result, equation (11) can be restated as

$$Cg = g'(p_1, p_1', p_2, y, \theta, \bar{x}_1)$$

or

$$Cg = \min\{g(p_1, p_2, y, \theta); h'(p_1', p_1, p_2, y, \bar{x}_1, \theta)\} \quad . \tag{12}$$

Thereby a situation of multiple equilibria arises from (12). It is also true that there exists a subsegment of the budget constraint which can never contain global equilibrium. A diagrammatical proof is given in appendix I.

(iii) A convex budget set

Let the pricing of x_1 be defined as follows. Any $x_1 \le \bar{x}_1$ is purchased at a given price p_1 whereas extra quantities are purchased at a higher unit price $p_1' > p_1$. The resulting budget set is convex. Because of that and given the convexity of the production function the following proposition can be stated.

Proposition 4. *Once a tangency point is found between a given isoquant and a segment of an isocost no tangency point exists on the other segment. If, however $g(.)$ does not exist $g'(.)$ may, or may not exist and vice versa. If neither $g(.)$ nor $g'(.)$ exist then $Cg = h(.)$.*

The latter is true for the subset of the parameter space, for which, optimisation in the absence of the inequality constraint would lead to equilibrium to the right of $\bar{x}_1$ under regime p_1 and to the left of $\bar{x}_1$ under regime p_1'.

It follows from proposition 4 that no case of multiple equilibria exist. Also any point on the budget constraint may represent the cost minimizing quantity bundle. $\bar{x}_1$ is a concentration point since $\partial x_1/\partial p_1|_{x_1=\bar{x}_1} = 0$ and $\partial x_1/\partial y|_{x_1=\bar{x}_1} = 0$ for a whole range of values of the parameters for which $Cg = h(.)$ remains true. As a result the global cost function takes the form

$$Cg = g(p_1, p_2, y, \theta)$$

or

$$Cg = g'(p_1, p_1', p_2, y, \theta, \bar{x}_1)$$

or

$$Cg = h(p_1, p_2, y, \theta, \bar{x}_1) \tag{13}$$

2.2. Ordering equilibria by output under a non-convex budget set

(i) The non-convex case

Recall from (10) that, given the tariff structure, we have: $g(.) < g'(.)$ or $g(.) > g'(.)$ or $g(.) = g'(.)$, depending on y and θ Treating θ as fixed, let us examine whether the level of output divides behaviour. In particular, we want to answer the following question.

Under what conditions there exists a critical value of y, say y^*, for which, other things being equal, one regime is optimal when $y < y^*$ and the other regime is optimal when $y > y^*$.

Let us write the multiple equilibria equation as:

$$C(p_1, p_2, y, \theta) = C'(p_1, p_1', p_2, y, \theta)$$

or $$F(p_1, p_1', p_2, y, \theta, \bar{x}_1) = 0 \qquad (14)$$

Suppose there is a value of y, y^*, that solves (14). At $y = y^*$ the optimizing agent will be indifferent between the two regimes. Assuming it is unique y^* is also the critical level of y, as defined above. The necessary condition on (14) is to define a function

$$y = f(p_1, p_1', p_2, \bar{x}_1, \theta) \quad . \qquad (15)$$

For such a function to exist, it is required that F has continuous partial derivatives F_{p_1} ,..., $F_{\bar{x}_1}$ and F_y is nonzero for any y^* satisfying F.

The sufficient condition for a global division of behaviour is

$$F_{y^*} > 0 \quad \text{all } y^* \quad \Leftrightarrow \quad \partial C/\partial y^* > \partial C'/\partial y^*$$

or $$F_{y^*} < 0 \quad \text{all } y^* \quad \Leftrightarrow \quad \partial C/\partial y^* < \partial C'/\partial y^* \qquad (16)$$

The question arising at this point concerns the restrictions imposed by the above conditions on the form of production technology.

Proposition 5. *Under equilibrium defined by (9), y^* defines a global division of behaviour iff the partial derivative of the cost function, with respect to y is monotonic in p_1, or equivalently, the demand function for x_1 is monotonic in y. The proof is obvious. Given (8) and (14), monotonicity of $\partial C/\partial y$ in p_1 implies (16). Furthermore the following results hold.*

Lemma 1. *If $\partial^2 C/\partial y \partial p_1 = \partial x_1/\partial y > 0$ all p_1, p_1', p_2, y equilibrium is on regime p_1/p_2 for all $y < y^*$ and on regime p_1'/p_2 for all $y > y^*$*

Lemma 2. *If $\partial^2 C/\partial y \partial p_1 = \partial x_1/\partial y < 0$ all p_1, p_1', p_2, y equilibrium is on regime p_1'/p_2 for all $y < y^*$ and on regime p_1/p_2 for all $y > y^*$*

Given these results, we can now examine whether certain types of technology satisfy (16).

(a) Homothetic type of technology

Homothetic technology conveys the following cost function

$$C = h(y)g(p) \qquad (17)$$

where $h(y)$ is required to be positive and increasing in y and $g(p)$ positive and increasing in p. The multiple equilibria equation F and its derivative with respect to y, F_y, can be written as

$$F = h(y)g(p_1, p_2) - h(y)g(p_1', p_2) - \bar{x}(p_1 - p_1') = 0$$
$$F_y = \partial h/\partial y\, g(p_1, p_2) - \partial h/\partial y\, g(p_1', p_2) \qquad (18)$$

However since $p_1 > p_1'$ and $h(y)$ positive and increasing, it follows that $F_y > 0$ everywhere. Therefore, for any homothetic production structure, there exists a level of output which divides behaviour according to lemma 1.

(b) Non-homothetic technology exhibiting linear expansion paths

$$C = h(y)l(p) + k(p) \qquad (19)$$

For $l(p)$ increasing in p_1, there exists a y^* that divides behaviour according to lemma 1, whereas for $l(p)$ decreasing in p_1, y^* divides behaviour as in lemma 2. If however, $\partial l(p)/\partial p_1 = 0$, i.e expansion paths are vertical, equilibrium is always on the same regime. Assuming further that the configuration of prices results in $C(.) = C'(.)$ at $y = y^*$, vertical expansion paths imply that multiple equilibria is sustained for every output level.

(c) Technology characterised by non-linear expansion paths

Let us assume that operation at a larger scale increases the efficiency of x_1. As a result it becomes more profitable for the optimizing agent to increase its intensity. In other words let

$$\partial(MRS)/\partial y|_{(x_2/x_1)} > 0 \quad \text{or} \quad \partial(x_2/x_1)/\partial y|_{(p_1/p_2)} < 0 \qquad (20)$$

Since a necessary condition for (20) is that $\partial x_1/\partial y > 0$, all x_2/x_1, p_1/p_2 it follows that, if (20) is true, there exists a level of output y^* that divides behaviour according to lemma 1 (see Figure 1.a).

Now, assume that operation at a larger scale increases the efficiency of x_2 and thereby price and technology effects work in opposite directions. In other words let

$$\partial(MRS)/\partial y|_{(x_2/x_1)} < 0 \quad \text{or} \quad \partial(x_2/x_1)/\partial y|_{(p_1/p_2)} > 0 \qquad (21)$$

Under the above condition the two regimes may not be globally ordered by output level. Figure 1.b illustrates a situation where two cases of multiple equilibria occur at y^* and y^{**}. As a result regime p_1/p_2 is optimal for two disjoint intervals.

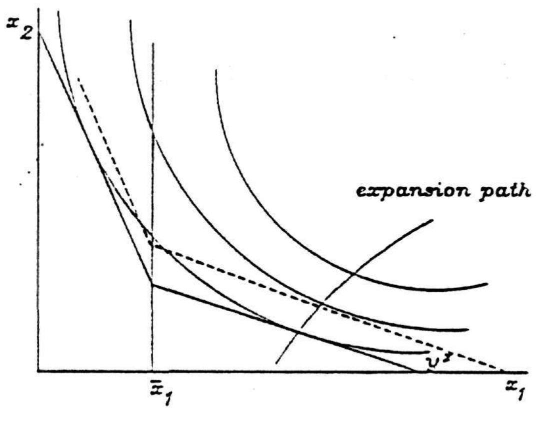

Figure 1.a

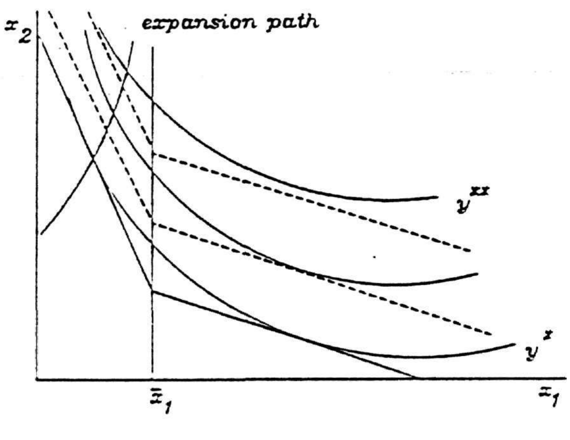

Figure 1.b

2.3. Ordering of regimes under discontinuous and convex budget sets

It was shown earlier that under discontinuous or convex piece-wise linear budget sets, economic behaviour is represented by one of three alternative cost functions depending on the parameters. Ordering equilibria by output is thereby linked to the existence of two critical levels of y. It follows from proposition 3, that the question of relating a range in the output space to equilibrium defined by $g'(p_1', p'_2, y)$ reduces to the question of finding a range in the output space for which $g'(p_1', p'_2, y)$ exists. As a result the whole question of division of behaviour can be restated as follows.

(i) Under what conditions the output space for which $g'(.)$ *exists is a unique interval ?*

(ii) Under what conditions the complementary to that interval set can be uniquely divided into a subset related to global equilibrium on the first price regime and a subset related to global equilibrium on the kink point?

Monotonicity of input demand function for x_1 in output is obviously a necessary and sufficient condition for (i). Moreover, the following diagrammatical argument shows that the same condition is necessary and sufficient for (ii) as well. Let y_0 represent the output level for which $g(.) = h(.)$ at $C = C_0$ Let us further assume that the first segment of a higher isocost C_1 is tangent to a higher isoquant y_1. If $\partial x_1 / \partial y > 0$ all p_1, p_2, y it follows by convexity of the production function that the second segment of C_1 will intersect y_1 at a point to the right of $\bar{x}_1$. Hence, for any level of output higher than y_0, $h(.) < g(.)$ is true. If, however, $\partial x_1 / \partial y < 0$ all p_1, p_2, y the argument is reversed. Therefore, the following proposition holds.

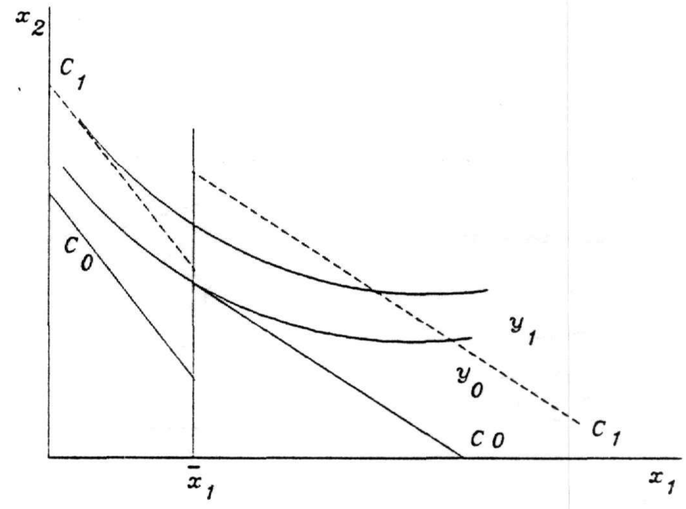

Figure 2

Proposition 6. Under the discontinuous piece-wise linear budget set, resulting in (11), monotonicity of $x_1(p_1, p_2, y)$ *in* y *is necessary and sufficient condition for ordering equilibria by output.*

Lemma 3. Under (12), if $\partial x_1/\partial y > 0$ *then* $F = g(.) - h(.) = 0$ *defines a critical level of output* y^* *such that* $y < y^*$ *implies* $Cg = g(.)$ *and* $y > y^*$ *implies* $Cg = h(.)$. *Also* $\bar{x}_1 - x_1(p_1', p_2, y) = 0$ *defines a critical level of output* $y^{**} > y^*$ *such that* $y > y^{**}$ *implies* $Cg = g'(.)$. *If, however,* $\partial x_1/\partial y < 0$ *then* $y^* > y^{**}$ *and the order of equilibria by output level is reversed.*

Turning now to the case of the convex budget set defined by (13), it follows from proposition 4, by a reasoning analogous to that advanced for the discontinuous case, that monotonicity of $x_1(.)$ with respect to y is a necessary and sufficient condition for ordering equilibria by output. In particular:

Lemma 4. Under a convex budget set resulting in (13), if $\partial x_1/\partial y > 0$, *then equation* $F = \bar{x}_1 - x_1(p_1, p_2, y) = 0$ *defines a critical level of output* y^* *such that* $y < y^*$ *implies* $Cg = g(.)$. *Also* $\bar{x}_1 = x_1(p_1', p_2, y)$ defines a critical level of output $y^{**} > y^*$ *such that* $y > y^{**}$ *implies* $Cg = g'(.)$. *If, however,* $\partial x_1/\partial y < 0$ *then* $y^* > y^{**}$ *and the order of equilibria by output level is reversed.*

3. ORDERING EQUILIBRIA BY OUTPUT IN THE CASE OF N BLOCKS

Let us now assume that x_2 is purchased at the fixed price p_2, whereas, x_1 is subject to an n-segment linear price schedule. Introducing some extra notation let us denote by $\bar{x}_1^i$ the upper bound of the ith block where $\bar{x}_1^1 < \bar{x}_1^2 < \ldots < \bar{x}_1^{n-1}$ and by p_1^i $i = 1 \ldots n$ the price of x_1 in the ith block.

Since each isocost has n linear segments there are, in effect, n separate minimisation problems to be considered. The cost function representing global optimum is derived by comparing n local functions and is simply a generalisation of the two-block case for each particular type of budget set.

The question of interest is whether the conditions ensuring ordering of regimes by output, in the case of two blocks, suffice for a unique ordering when the number of blocks equals n. We therefore maintain throughout this section that production technology satisfies the condition $\partial x_1/\partial y > 0$ everywhere in p, y.

3.1. The convex case

The case of a convex budget set defined by $p_1^1 < p_1^2 < \ldots < p_1^n$ is quite straightforward. For any arbitrary kink point k a lower and an upper critical level of y, y^*_{KL} and y^*_{KU} are defined by $\bar{x}_1^k - x_1(p_1^k, p_2, y) = 0$ and $\bar{x}_1^k - x_1(p_1^{k+1}, p_2, y) = 0$ respectively, such that, for $y < y^*_{KL}$ equilibrium is on regime relating to $p_1 \leq p_1^k$, for $y^*_{KL} < y < y^*_{KU}$ equilibrium is given by $\bar{x}_1^k$ and for $y > y^*_{KU}$ equilibrium is on regime relating to $p_1 \geq p_1^{k+1}$. Consideration of blocks to the right and left of k leads to the following result.

Proposition 7. Under a convex budget set defined by $p_1^1 < p_1^2 < \ldots < p_1^n$, $\partial x_1/\partial y > 0$ ensures the existence of $2(n-1)$ critical values of y, $y^*_{1L} < y^*_{1U} < y^*_{2L} < y^*_{2U} < \ldots < y^*_{(n-1)L} < y^*_{(n-1)U}$, which order equilibria in the following manner. For $y < y^*_{KL}$ equilibrium is on regime k, for $y^*_{KL} < y < y^*_{KU}$ equilibrium is given by $\bar{x}_1^k$ and for $y > y^*_{KU}$ equilibrium is on regime $[k+1]$.

3.2. The non-convex case

Extension of the two block results to the n block case is not straightforward within a non-convex framework. However, if regimes are to be ordered by output, certain critical levels, relating to multiple equilibria situations, should be identified.

We can demonstrate a situation involving n blocks through a three-block example defined by $\bar{x}_1^1 < \bar{x}_1^2$ and $p_1^1 > p_1^2 > p_1^3$.

Denote by C_1, C_2, C_3 the cost function at a local optimum on the first, second and third regimes, respectively. Three situations of equality between pairs of interior local optima emerge.

$$F = C_1 - C_2 = 0 \quad \text{defining} \quad y_{12} = f(p_1^1, p_1^2, p_2, \theta, \bar{x}_1^1)$$
$$F = C_1 - C_3 = 0 \quad \text{defining} \quad y_{13} = f(p_1^1, p_1^2, p_1^3, p_2, \theta, \bar{x}_1^1, \bar{x}_1^2)$$
$$F = C_2 - C_3 = 0 \quad \text{defining} \quad y_{23} = f(p_1^2, p_1^3, p_2, \theta, \bar{x}_1^2) \tag{22}$$

However, equality of local optima does not in itself imply multiplicity of equilibria. The latter, denoted by y_{ij}^*, presupposes $C_i = C_j < C_k$, for $i, j, k = 1, 2, 3$ and $i \neq j \neq k$

To come to a more definite conclusion about possible situations of multiple equilibria it is necessary to examine more carefully the relations among local optima.

Since y_{12}, y_{13}, y_{23} are functions of different set of arguments, they may relate to each other in various ways. Let H, be the set which includes all possible combinations of ordering y_{ij}. In our example, H takes the following form

$$H = \left\{ \begin{matrix} R_1 = (y_{12} < y_{13} < y_{23}), R_2 = (y_{12} < y_{23} < y_{13}), R_3 = (y_{13} < y_{12} < y_{23}), R_4 = (y_{13} < y_{23} < y_{12}) \\ R_5 = (y_{23} < y_{12} < y_{13}) R_6 = (y_{23} < y_{13} < y_{12}), R_7 = (y_{12} = y_{13} = y_{23}) \end{matrix} \right\} \tag{23}$$

Our problem is to select the subset of feasible orderings, that is the set including all possible situations that do not violate the maintained assumption of a unique ordering of regimes when a pair of adjacent blocks is considered in isolation. To do so we have to rule out not feasible alternatives.

Recall from the two-block case that for any pair of blocks, i, j, $j > i$, there exists a y_{ij}, defined by $C_i - C_j = 0$, such that, for all $y > y_{ij}$, $C_j < C_i$ is true and for all $y < y_{ij}$, $C_i < C_j$ is true. When a third block k, $k \neq i, j$, is brought into the comparisons y_{ij} may or may not relate to global equilibrium, depending on the corresponding C_k. However, a number of statements can be shown to be true, for any given set of parameters, maintaining $j > i$.

Lemma 5. *For any y_{ij} defined by $C_i = C_j > C_k$ the following hold true.*

(a) If $k > i, j$ then $y_{ik} > y_{ij}$ and $y_{jk} > y_{ij}$ are not possible.

(b) If $k < i, j$ then $y_{ki} > y_{ij}$ not possible for y_{ki} defined by $C_k = C_i < C_j$ and $y_{kj} > y_{ij}$ is not possible for y_{kj} defined by $C_k = C_j > C_i$.

(c) If $i < k < j$ then $y_{ik} > y_{ij}$ is not possible.

Lemma 6. *For any y_{ij} defined by $C_i = C_j < C_k$ the following hold true.*

(a) If $k > i, j$ then $y_{ik} > y_{ij}$ is not possible for y_{ik} defined by $C_i = C_k < C_j$.

(b) If $k < i, j$ then $y_{ki} > y_{ij}$ and $y_{kj} > y_{ij}$ are not possible.

(c) If $k > i, k < j$ then $y_{kj} > y_{ij}$ is not possible for y_{ik} defined by $C_i = C_k < C_j$.

The above statements follow directly from the two-block results. The proof is given in appendix II.

On the basis of these results we can examine each element of H with in order to select the feasible set. Given any y_{ij} associated with either local or global optimum, we examine whether the situations represented by the remaining elements in R can also arise in the specified order. As shown in appendix III the feasible set H_f is reduced to

$$H_f = \{R_1, R_6, R_7\} \tag{24}$$

Obviously for any given set of values of parameters one of the three elements in (24) is true, each one being associated with a different set of global optima with the exception of the limiting case R_7 which is equivalent to R_6 in terms of the implied ordering of regimes and thereby can be ignored.

Figures 3.a and 3.b represent the two alternatives. In particular figure 3.a represents the situation resulting when R_1 is true and equilibrium is ordered in terms of two critical levels of output y^*_{12} and y^*_{23}. In figure 3.b R_6 is true and equilibrium is ordered in terms of y^*_{13} .

The three-block example shows that ordering of regimes in the n-block case is not unique, under non-convex budget set, even if conditions for unique ordering by output in a two-block set-up hold. However regimes can still be ordered by output level, for any given set of parameter values, as long as each feasible ordering of output levels, defined by equality of local optima, is linked to a particular ordering of regimes.

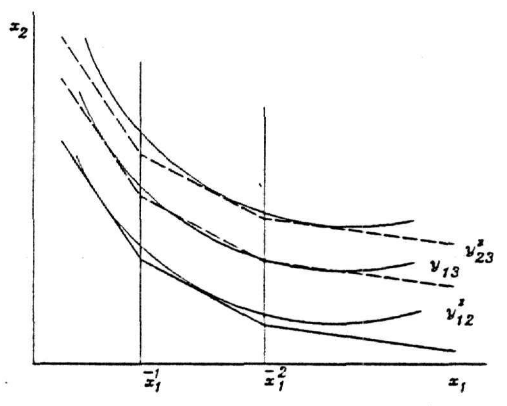

Figure 3.a

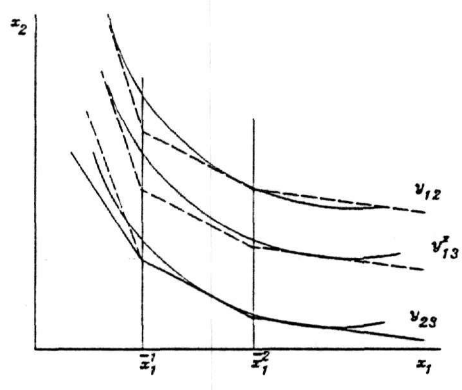

Figure 3.b

The above conditions were shown to hold for the tree-block example and can be shown to hold for the n-block case. .

Proposition 8. *Under a non-convex budget set defined by structure* $\bar{x}_1^1 < \ldots < \bar{x}_1^{(n-1)}$ *and* $p_1^1 > \ldots > p_1^n$, *the set of alternative situations of ordering regimes by output contains* A *elements where* $A = (n-2) + \frac{(n-2)(n-3)}{2!} + \frac{(n-2)(n-3)(n-4)}{3!} + \ldots + \frac{(n-2)!}{(n-3)!}$.

This proposition is simply an extension of the three block results and indicates that a certain segment of the budget constraint, or any combination of interior segments may not contain equilibrium. But can those alternatives be uniquely associated with certain orderings of multiple local optima?

Proposition 9. *If* $y_{12} < y_{23} < \ldots < y_{(n-1)n}$ *then each output level representing equality of adjacent local optima represents also a multiple equilibria situation. As a result regimes are ordered by output accordingly.*

The above statement falls back to the proof of the feasibility of R_1 when all possible sets of three adjacent blocks are considered.

Proposition 10. *If* $y_{k(k+1)} > y_{(z-1)(z)}$, *where* k, z *are positive integers and* $z > k$ *then* y^*_{kz} *represents a critical level of output indicating that equilibrium relates to* $x \le \bar{x}_1^k$ *for lower levels of output and to* $x \ge \bar{x}_1^z$. *for higher levels. Regimes* $k+1, \ldots, z-1$ *do not contain global equilibrium.*

The proof of this statement follows from the two block results. By lemmas 5.b and 6.b $y_{k(k+1)} > y_{(z-1)(z)}$ is possible if neither case represents global equilibrium. Under this set-up it follows that, at $y_{(z-1)(z)}$, C_k represents the global optimum and, at $y_{k(k+1)}$, C_z represents the global optimum. For $y_{(z-1)(z)} < y < y_{k(k+1)}$ C_k and C_z are lower than cost associated with any other local optimum. Therefore there exists, within the above range, an output level y^*_{kz} which represents global multiple equilibria.

The above show that under a non-convex budget set involving n blocks, regimes can still be ordered by output level, the specific ordering depending on the particular parameter set.

4. ORDERING POSSIBLE EQUILIBRIA BY TECHNOLOGY

Suppose now that the level of output is given for the firm and consider whether equilibrium can be associated with a certain price regime, according to technological characteristics. Let production technology be represented by a given parametric form , or approximated by a certain approximating function. A practically meaningful variation in technology can be defined in terms of a variable parameter vector.

In a two-input technology represented by the cost function $C=g(p_1,p_2,y,\theta)$ let θ denote a single parameter and assume that θ^* solves the multiple equilibria equation $F(\theta^*,p_1,p_1^{'},p_2,\bar{x},y)=0$. For θ^* to divide behaviour it must be true that F defines a function

$$\theta^*=\theta(p_1,p_1^{'},p_2,y,\bar{x}_1) \tag{25}$$

and that the following condition holds for any value of the parameters solving F.

$$\partial F/\partial\theta^*>0 \text{ or } \partial F/\partial\theta^*<0 \tag{26}$$

In order to specify the type of production or cost functions that satisfy the above conditions we must examine the restrictions they impose on the technological parameter θ To do so we may distinguish two cases:(a) the class of cost functions monotonic in θ and (b) the class of cost functions not monotonic in θ.

Technologies included in the first category exhibit isoquants which do not intersect as θ varies. Ordering of regimes by θ in this case, is obviously governed by conditions directly analogous to those obtained in relation to ordering regimes by output. Hence,

Proposition 11. *If* $C=g(p_1,p_2,y,\theta)$ *is monotonic in* θ, θ^* *divides behaviour if* $\partial x_1/\partial\theta>0 \;\forall\; \theta, p_1/p_2$, *or* $\partial x_1/\partial\theta<0 \;\forall\; \theta, p_1/p_2$.

The analogous of lemma 1 and lemma 2 can be trivially stated.

Technological structures resulting in linear in parameters input demand functions form a subset of models belonging in class (a). Consider for example the quadratic cost function (Lau, 1974).

$$C=(a_0+a_1p_1+a_{11}p_1^2+a_2p_2+a_{22}p_2^2+a_{12}p_1p_2)h(y) \; . \tag{27}$$

The demand function for x_1 takes the form

$$x_1=(a_1+2a_{11}p_1+a_{12}p_2)h(y). \tag{28}$$

Obviously all three parameters in (28) divide behaviour since $\partial x_1/\partial a_1, \partial x_1/\partial a_{11}, \partial x_1/\partial a_{12}$ satisfy condition (26) for all p_1, p_2, y.

Consider now category (b) above. Models in this set exhibit isoquants which, other things being equal, intersect each other as θ varies. It can be shown that for condition (26) to hold, isoquants from different technologies must only cross once. Figure 4 demonstrate this point.

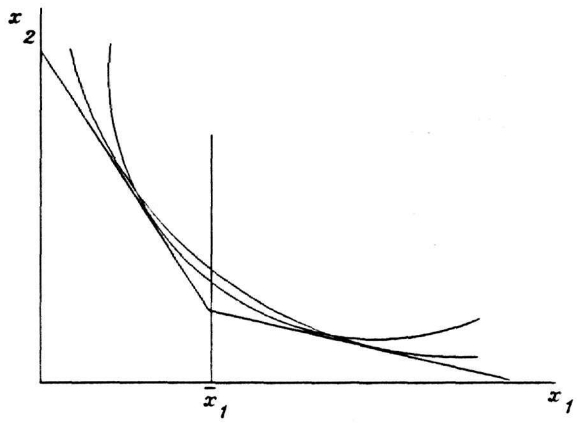

Figure 4

Both θ^* and θ^{**} represent situations of multiple equilibria given the output level. Each regime however is optimal for two disjoint intervals, hence, possible equilibria cannot be globally ordered by θ.

Let us now assume that isoquants from different technologies have a single common point. In our two input paradigm such a condition implies that there exist a value of $[x_1, x_2] = [\bar{x}_1, \bar{x}_2]$ such that,

$$f(\bar{x}_1, \bar{x}_2, \theta_i) = f(\bar{x}_1, \bar{x}_2, \theta_j) \quad \forall \quad i, j \tag{29}$$

We can again distinguish two different subsets: (i) isoquant θi lies entirely above θj except for point $[\bar{x}_1, \bar{x}_2]$ and (ii) isoquant θ_i lies above θj for $x_1 < \bar{x}_1$ and $x_2 > \bar{x}_2$ and below θj for $x_1 > \bar{x}_1$ and $x_2 < \bar{x}_2$.

Consider first case (i). As figures 5.a and 5.b show MRS remains constant along the A ray through point $[\bar{x}_1, \bar{x}_2]$. For any ray through the origin to the left of A, MRS increases with θ and for any ray through the origin to the right of A, MRS decreases as θ takes higher values. Let θ^* be the multiple equilibria situation. In figure 5.a for any $\theta > \theta^*$ equilibrium is on the first regime and for any $\theta < \theta^*$ equilibrium is on the second regime. In figure 5.b however regimes are ordered in the opposite way. Obviously the actual outcome depends on whether $[\bar{x}_1, \bar{x}_2]$ lies to the left, or to the right of $\bar{x}$. Hence,

***Proposition* 12.** *If MRS remains constant along a given ray through the origin, increases to the left and decreases to the right as θ takes higher values, equilibrium cannot be globally ordered by θ.*

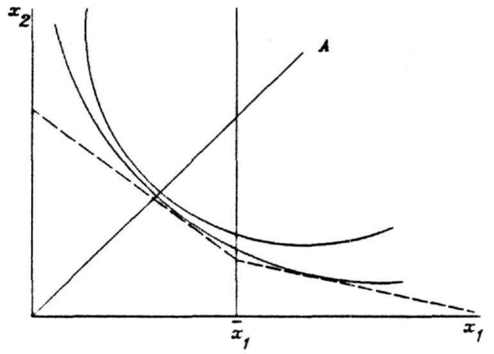

Figure 5.a

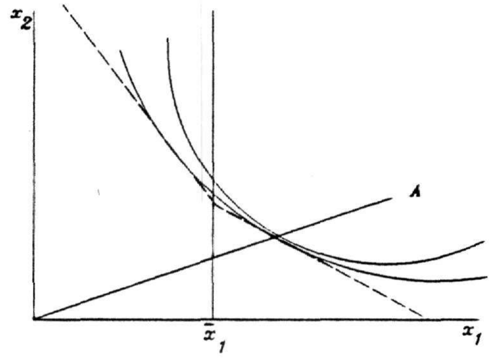

Figure 5.b

In case (ii) MRS increases or decreases along each ray through the origin as θ takes higher values. Figure 6 illustrates how behaviour is divided in this case. Let a be the ray on which $MRS = p_1/p_2$ at $\theta = \theta^*$ and b the ray on which $MRS = p_1'/p_2$ at $\theta = \theta^*$. For $\theta > \theta^*$, MRS increases on every ray through the origin. As a result, both a and b shift to the right at a' and b' respectively. The new equilibrium point is on b' since it relates to a lower isocost.

It is however possible to envisage configurations of parameters that do not lead to the above result. If for example the point of intersection between isoquants is very close to the x_2 axes and $\bar{x}_1$ assumes a relatively high value the situation becomes very similar to that of figure 1.b. Therefore,

***Proposition* 13.** *If $C = g(p_1, p_2, y\theta)$ is non monotonic in θ, the necessary condition for θ^* to divide behaviour is $\partial(MRS)/\partial(\theta) > 0$ or $\partial(MRS)/\partial(\theta) < 0$ all x_1/x_2. The sufficient condition is $\partial x_1/\partial\theta \neq 0$ for all $\theta, p_1/p_2$.*

The above results can be demonstrated by means of two common parametric examples, the Cobb Douglas (CD) and the CES. As shown in appendix IV, CES is a type (i) model with relation to the substitution parameter. CD, on the other hand, is a type (ii) model and the production parameter divides behaviour under constant returns to scale.

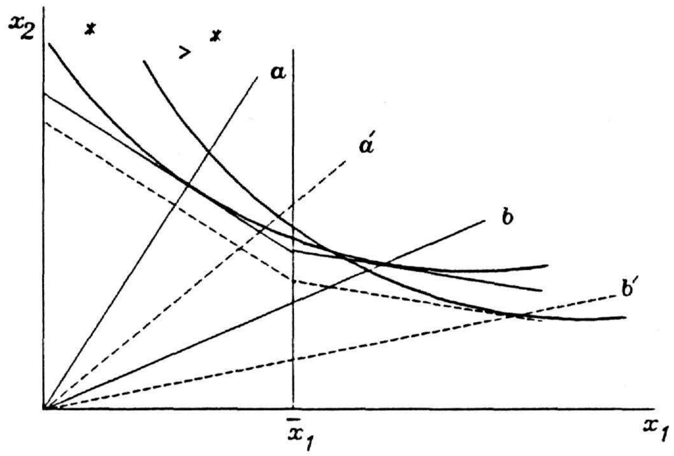

Figure 6

The introduction of n blocks can be analysed in a way similar to the case of ordering regimes by output, leading to directly analogous results and will not pursued here.

5. RELEVANCE OF THE RESULTS

The results obtained in the previous sections have a number of interesting empirical implications regarding the econometrics of non-linear pricing as well as the designing optimal price structures.

Econometric implications are obvious. Ordering of regimes by either output or technology may be employed in designing algorithms for obtaining global optima.

Consider first the most straightforward application, namely the one based on the assumption of constant technology. If no ordering of regimes by output level is utilised, an algorithm for obtaining global optimum amounts to performing the optimization exercise for each linear segment of the budget constraint. In a cost minimization context, and for any given set of parameters, such an exercise involves calculation of the value of the cost function associated with each linear segment of the budget constraint, derivation of the associated demand for inputs, comparison to critical quantities contained in the price structure and - unless the budget set is convex - comparison of relevant local optima to select global optimum. If however price regimes are ordered by output level, global optimum can be readily obtained on the basis of output information since in order to select the relevant price regime it is only necessary to calculate the critical levels of y and compare them to actual output. The computational advantage of the second approach turns out to be a very significant one for many actual situations in which individual agents face the same tariff structure, as it is the case for electricity, telephone and other utilities.

Limited price variation is however present in most empirical applications relating to cross sectional data. This fact highlights the significance of those approaches which attribute a part of demand variation to differences in technology or preferences. Hausman's approach is a case in point. His method has not, however, been applied by other researches, despite the obvious richness of insights and interpretations associated with the assumed parameter variation, probably due to the fact that the framework within which it can be applied has remained unclear. In addition to that Hausman's own applications involve the complexity of non-analytical critical parameter values. Our results on ordering regimes by technology indicate that there is scope for employing parameter variation within a rather general framework, thereby enhancing the robustness of the variable parameter method.

Finally ordering of regimes by output may be extremely useful in designing optimal tariff structures for a number of utilities which traditionally supply price their products on the basis of multisegment price schedules.

6. CONCLUSIONS

Cost minimizing decisions of neoclassical firms, in the face of non-linear pricing lead to non-analytical input demand functions which do not comply to all conventional comparative statics results. Full characterisation of behaviour, however, often requires a classification of equilibria. The present paper explores the question of classifying equilibria by output level and by technology.

Conditions on technological structure, for ordering equilibria by output, are derived for the two-block case, under convex, no-convex and discontinuous budget sets. Those conditions imply that regimes can be ordered by output within a rather wide range of technological structure.

Similarly we derive conditions for ordering price regimes by a single technological parameter. The results show that regimes can be order in terms if input demand functions are monotonic with respect to that parameter.

It is further shown that the conditions necessary for ordering of regimes in a two block set-up suffice for ordering of regimes in a multisegment context.

Finally the results obtained are shown to be highly relevant in empirical work.

APPENDIX

I *Discontinuous budget set.*

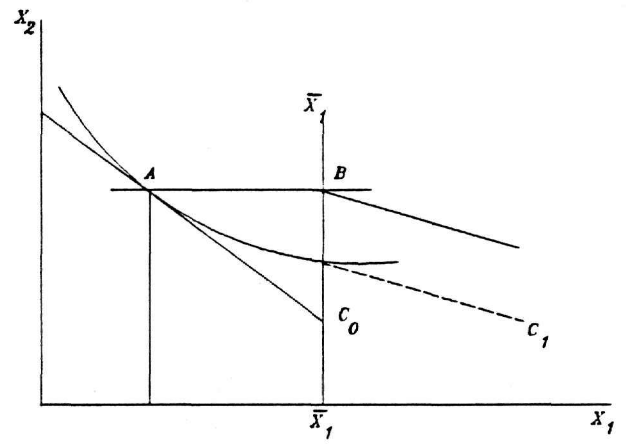

Figure 7

Let AB be parallel to the horizontal axes and pass through the kink point. Suppose A represents a local optimum on the first segment. By monotonicity and convexity of production function, y_0 will intersect $\bar{x}_1\bar{x}_1$ at a point below B. Hence A cannot represent the global minimum. Since the argument is valid for the entire AC_0 subsegment proposition 6 is true.

II *Proof of Lemmas 5 and 6.*

Proof of lemma 5: C_k at $y = y_{ij}$ is global minimum. Thus for $k > i, j$ any $y > y_{ij}$ is associated with $C_k < C_i$ and $C_k < C_j$. Hence lemma 5.a. For $k < i, j$ any $y > y_{ij}$ is associated with $C_j < C_i$ hence lemma 5.b. Finally for $i < k < j$ any $y > y_{ij}$ is associated with $C_k < C_i$ hence lemma 5.c.

Proof of lemma 6: $C_i = C_j$ at $y = y_{ij}$ represent global minimum. As a result for $k > i, j$ any $y > y_{ij}$ is associated with $C_j < C_i$ hence lemma 6.a. For $k < i, j$ any $y > y_{ij}$ is associated with $C_j < C_i$ and $C_j < C_k$. Hence lemma 6.b. Finally for $i < k < j$ any $y > y_{ij}$ is associated with $C_j < C_i$ and $C_j < C_k$. Also any $y < y_{ij}$ is associated with $C_i < C_j$ and $C_i < C_k$. Hence lemma 6.c.

III *Proof of equation (24).*

For the sake of simplicity, in what follows we shall refer to y_{ij} as local or global, depending on whether it is defined by the equality of local or global optima, respectively.

R_1 : If y_{12} is local, then $y_{13} > y_{12}$ is not possible by 5.a. If on the other hand y_{12} is global then $y_{13} > y_{12}$ may arise only if y_{13} is local in which case $y_{23} > y_{13}, y_{12}$ is possible only if y_{23} is global. Therefore, R_1 is a feasible ordering.

R_2 : If y_{12} is local, then $y_{23} > y_{12}$ does not exist by 5.a. If y_{12} is global, then $y_{23} > y_{12}$ may arise only if y_{23} is global, but then $y_{13} > y_{23}$ does not exist by 6.b, therefore R_2 is not feasible.

R_3 : If y_{13} is local, then $y_{12} > y_{13}$ does not exist by 5.c. If y_{13} is global, then $y_{12} > y_{13}$ may arise only if y_{12} is local, but in that case $y_{23} > y_{12}$ does not exist by 5.a, therefore R_3 is not feasible.

R_4 : If y_{13} is local, then $y_{23} > y_{13}$ is possible but $y_{12} > y_{13}$ does not exist by 5.c. If y_{13} is global then, $y_{23} > y_{13}$ does not arise by 6.c, therefore R_4 is not feasible.

R_5 : If y_{23} is local, then $y_{12} > y_{23}$ is possible only if y_{12} is local (5.b) but then $y_{13} > y_{12}$ is not possible by 5.a. If y_{23} is global then, $y_{12} > y_{23}$ does not arise by 6.b, therefore R_5 is not feasible.

R_6 : If y_{23} is local, then $y_{13} > y_{23}$ is possible if y_{13} is global by 5.b. Also $y_{12} > y_{23}$ is possible if y_{12} is local by 5.b and $y_{12} > y_{13}$ is possible if y_{12} is local by 6.a. Æherefore R_6 is feasible.

R_7 : Obviously R_7 is feasible representing a limiting case.

IV *Ordering regimes by technology in a Cobb-Douglas (CD) and CES context.*

Assuming constant returns to scale CD production and cost function can be written as follows

$$y = x_1^{\alpha} x_2^{1-\alpha}$$

$$C_g = y p_1^{\alpha} p_2^{1-\alpha} (1 - \alpha/\alpha)^{\alpha} (1/1 - \alpha)$$

It can be shown, letting $y(\alpha_i, x_1, x_2) = y(\alpha_j, x_1, x_2)$ that isoquants representing the same level of output but different values of α have a common point at $x_1 = x_2 = y$. Furthermore,

$$MRS = (x_2/x_1)(\alpha/1 - \alpha)$$

and $$\partial(MRS)/\partial\alpha|_{x_2/x_1} = (x_2/x_1)(1/1 - \alpha)^2 > 0$$

Therefore CD represents a case (ii) model satisfying the necessary condition for division of behaviour by α. To examine whether the sufficient condition also holds it is necessary to work out the derivative of multiple equilibria equation.

$$F = C_g(p) - C_g(p') = \frac{1}{1-\alpha}\left(\frac{\alpha}{1-\alpha}\right)^{\alpha} p_2^{1-\alpha} - \left(\frac{\bar{x}_1}{y}\right)\left(\frac{p_1 - p_1'}{p_1^{\alpha} - (p_1')^{\alpha}}\right) = 0$$

For α^* to divide behaviour, F_α must be either positive or negative for any set of values satisfying F. Solving F for y and substituting into F_α we get

$$F_\alpha = \left[1 - \ln p_2 \quad + \quad \ln\left(\frac{\alpha}{1-\alpha}\right) \quad + \quad \frac{1}{1-\alpha} \quad + \quad \frac{p_1^{\alpha} \ln p_1 - p_1'^{\alpha} \ln p_1'}{p_1^{\alpha} - (p_1')^{\alpha}} \right] \quad \bar{x}_1 (p_1 - p_1')$$

Now it is obvious that F_α is always positive if the expression in the brackets is positive. However, for $0 < \alpha < 1$ the expression in the brackets is positive.

In the CES model we have $\qquad y = [\alpha x_1^{-\delta} + (1-\alpha) x_2^{-\delta}]^{-1/\delta}$

$$MRS = (x_2/x_1)^{\delta+1} \alpha/(1-\alpha)$$

It is trivial to show that for δ fixed and α variable, we get the same results as in the (CD) case. If α is assumed fixed and δ is allowed to vary, it can be shown, equating $y(\bar{x}_1, \bar{x}_2, \bar{\alpha}, \delta_i)$ to $y(\bar{x}_1 \bar{x}_2, \bar{\alpha}, \delta_j)$ that isoquants representing the same level of output have a common point at $x_1 = x_2 = y$. Working out $\partial MRS/\partial\delta$ we get

$$\partial MRS/\partial\delta|_{x_2/x_1} = (x_2/x_1)^{\delta+1} \alpha/(1-\alpha) \ln(x_2/x_1)$$

Therefore, other things being equal, as δ increases MRS remains unchanged along the ray $(x_2/x_1) = 1$, increases for $(x_2/x_1) > 1$ and decreases for $(x_2/x_1) < 1$ which indicates that CES is a type (1) model with respect to δ price regimes cannot be ordered unambiguously by δ.

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