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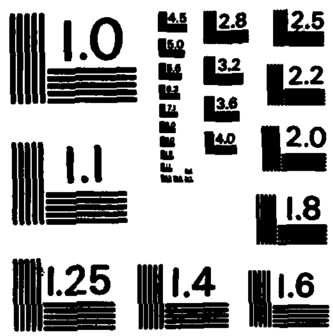

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OPTIMAL PRICE AND INCOME REGULATION UNDER UNCERTAINTY IN THE MODEL WITH ONE PRODUCER

by

MICHAEL I. TAKSAR

TECHNICAL REPORT NO. 379

August 1982

A REPORT OF THE
CENTER FOR RESEARCH ON ORGANIZATIONAL EFFICIENCY
STANFORD UNIVERSITY
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OPTIMAL PRICE AND INCOME REGULATION UNDER UNCERTAINTY
IN THE MODEL WITH ONE PRODUCER*

by

Michael I. Taksar**

1. Introduction

We consider an economic model with n consumers and only one producer. The producer can be viewed as a state sector of the economy which supplies consumers with q different products. The products can be merchandise as well as different types of labor. Supply can be positive and negative as well. E.g., negative supply of a labor to a consumer means that the consumer is working for the producer delivering that type of labor which he gets with negative sign. In our model the producer does not maximize his profit; therefore, taking into account the possibility of a negative supply, we may think of a model of a pure exchange economy in which the "state sector" plays a role of technological restriction on the economy as a whole.

The state governs the prices (common to everybody) and levies individual taxes. If the tax is negative, then the consumer gets a subsidy from the state equal to the absolute value of this tax.

Each consumer acts independently of the others maximizing his own utility function under budgetary constraints. The aim of the state is to find a feasible production plan which maximizes the sum of all utilities of individual consumers.

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We consider a multiperiod model without savings in which the main emphasis is on uncertainty.

2. Statement of the Results

In this section we give a precise mathematical formulation of the model considered.

Let $\mathbb{R}$ be a q-dimensional Euclidian space and let $Y \subset \mathbb{R}^N$. By $[Y]^t$ we denote the set of all $(y_1, y_2, \ldots, y_t$ such that $y_k \in \mathbb{R}$ and there exist $x_{t+1}, x_{t+2}, \ldots, x_N$ such that

$$(2.1) \qquad (y_1, y_2, \ldots, y_t, x_{t+1}, \ldots, x_N) \in Y \ .$$

Given $y_1, y_2, \ldots, y_t$, the set of all x_{t+1} for which there exist $x_{t+2}, \ldots, x_N$ satisfying (2.1) is denoted $[Y]_{t+1}(y_1, \ldots, y_t)$.

We have N periods of time, n consumers and one producer. The number of products is q, and a vector of $\mathbb{R}$ will be called a product-vector; the i-th coordinate of such a vector will be associated with the amount of the i-th product.

The state of nature at time t is described by a random variable s_t, taking values in a measurable space S, with σ-field F on it. The probability characteristics of the process $s_1, s_2, \ldots, s_t, \ldots$ are supposed to be known, i.e. a probability measure P on (S^N, F^N) is given. The bundle $(s_1, \ldots, s_t)$ is denoted s^t. The random variable s^t includes all the uncertainty up to time t, and the knowledge of this random variable gives us complete information about economic situations at time t. This variable is supposed to be known to all participants, but the future states of nature s_{t+1}, s_{t+2}, etc. can be only estimated.

<u>Consumers</u>. The consumer with number k is characterized by its consumption set

$$X^k \subset \mathbb{R}^N \times S^N$$

The section of X^k when $s^N \in S^N$ is fixed is denoted $X^k(s^N)$. Any $(x_1, x_s, \ldots, x_N) \in X^k(s^N)$ represents a sequence of product-vectors which can be consumed at times $1, 2, \ldots, N$ respectfully, given the state of the nature up to time N. The possibilities at time t should not depend on future development of the world and therefore $[X^k(s^N)]^t$ does not depend on $s_{t+1}, s_{t+2}, \ldots, s_N$. This set is denoted $X_t^k(s^t)$. The set $[X^k(s^N)]_t(x_1, \ldots, x_{t-1})$ we denote $X_t^k(s^t | x_1, \ldots, x_{t-1})$. This is a subset in $\mathbb{R}$, and its points are all the product-vectors which the k-th consumer can consume, given that the states of the nature in the 1st, 2nd, ..., t-th periods are described by s^t and the consumption at times $1, 2, \ldots, t-1$ was $x_1, x_2, \ldots, x_{t-1}$ respectfully.

The value of the consumption at time t for k-th consumer is described by the utility function $u_t^k(x, s^t)$, which associates a real number for each product-vector x given the state of nature up to time t.

The price-vector p is a q-dimensional vector and, given p, the cost of product-vector x is the inner product of p and x, this is denoted by px. The components of p can be both positive and negative. The latter means that the consumer is paid if he accepts certain kinds of products. At time t the k-th consumer receives α_t^k amount of money from the state (if α_t^k is negative then it means that he pays taxes). Given prices p_t and taxes α_t^k, the consumer maximizes his utility function subject to budgetary constraints, i.e., he solves the following problem: For each s^t find $x_t^k(s^t)$, such that

$$u_t^k(x_t^k(s^t), s^t) \to \max \tag{2.2}$$

subject to

$$p_t x_t^k(s^t) < \alpha_t^k(s^t) \tag{2.3}$$

$$x_t^k(s^t) \in X_t^k(s^t | x_1(s_1), \ldots, x_{t-1}(s^{t-1})) \tag{2.4}$$

where $x_1, x_2, \ldots, x_{t-1}$ are the consumption at times $1, 2, \ldots, t-1$.

Producer. The producer is characterized by its technological set

$$Y \subset \mathbb{R}^N \times S^N$$

The s^N-section of Y is a set of sequences $(y_1, y_2, \ldots, y_N)$. Any such sequence represents a set of products which can be brought to consumers by the producer at times $1, 2, \ldots, N$ respectfully, given that the state of the world up to time N is described by s^N.

We do not assume that the possibilities of production are independent in different periods of time, therefore $Y(s^N)$ is not supposed to be a product of N subsets of $\mathbb{R}$.

Just as in the case of consumption sets, we require that possibilities of production up to time t depend only on the state of nature up to time t, that is, $[Y(s^N)]^t$ depends only on s^t (this set will be denoted $Y_t(s^t)$). The set $[Y(s^N)]_t(y_1,y_2,\ldots,y_{t-1})$ is denoted $Y_t(s^t|y_1,\ldots,y_{t-1})$.

A production plan is a sequence of random vectors $y_1(s^1),y_2(s^2),\ldots,y_N(s^N)$, such that for each $s^N \in S^N$

$$(2.5) \qquad (y_1(s^1),\ldots y_n(s^N)) \in Y(s^N) \quad .$$

Another way of writing (2.5) is,

$$(2.6) \quad y_t(s^t) \in Y_t(s^t|y_1(s^1),\ldots,y_{t-1}(s^{t-1})) \quad , \quad t = 1,2\ldots,N \quad .$$

The verbal interpretation of (2.6) is the following. At each time t the producer decides what set of products he will produce during that period of time, this decision may be based on the state of the world up to time t, but not on the future values of the process $s_{t+1},s_{t+2},\ldots$ which are not known at time t. The production at time t must be technologically feasible, and the technological possibilities depend on the previous history of the world as well as on the previous production decisions.

Equilibrium. The main aim of the producer in this model is to find a production plan which maximizes the total expected utility of all consumers in the periods from 1 to N, that is, to solve the following problem

$$(2.7) \qquad E\{\sum_{i=1}^{n} \sum_{t=1}^{N} u_t^i(x_t^i(s^t),s^t)\} \to \max \quad .$$

Subject to

$$x_t^i(s^t) \in X_t^i(s^t | x_1(s^1),\dots,x_{t-1}(s^{t-1})) \quad , \tag{2.8}$$

$$t = 1,2,\dots,N \quad , \quad i = 1,\dots,n$$

$$(x_1(s^1),x_2(s^2),\dots,x_N(s^N)) \in Y(s^N) \tag{2.9}$$

where

$$x_t(s^t) = \sum_{i=1}^{n} x_t^i(s^t) \quad . \tag{2.10}$$

Let

$$\hat{x}_t^k(s^t) \quad , \quad t = 1,2,\dots,N \quad ; \quad k = 1,2,\dots,n$$

be the solution of the problem (2.7)-(2.10) and let

$$\tilde{x}_t^k(s^t) \quad , \quad t = 1,2,\dots,N \quad ; \quad k = 1,2,\dots,n$$

be the solution of the problem (2.2)-(2.4). If there exist prices $p_t(s^t)$ and individual taxes $\alpha_t^k(s^t)$ such that

$$\tilde{x}_t^k(s^t) = \hat{x}_t^k(s^t)$$

then we say that there exists an equilibrium and p_t and α_t^k are respectively equilibrium prices and taxes.

The meaning of this definition is the following. At each time t it is possible to set prices common to everybody p_t and individual taxes α_t^k in such a way that each consumer, maximizing his own utility function without regard to previous history or to any uncertainty in the future, will maximize the total expected utility of the whole society summed over all time periods. The prices and the taxes at time t can be chosen only on the basis of information available up to this time.

3. Proof of the main result.

In this section we prove the existence of equilibrium under the following assumptions:

A.1: For each k and each s^N the set $X^k(s^N)$ is a convex closed set in $\mathbb{R}^N$.

A.2: For each k and each s^N

$$\underline{0} \in X^k(s^N)$$

where $\underline{0}$ is a point in $\mathbb{R}^N$ with all coordinates equal to zero.

A.3: The sets $X^k(s^N)$ are uniformly bounded from below, i.e., there exists a vector $c \in \mathbb{R}^N$ (independent of k and s^N) such that for any $x \in X^k(s^N)$

$$x \geqq c \quad .$$

B.1: For each k the function $u^k(x,s^t)$ is measurable in (x,s^t).

B.2: For each k and any fixed s^t the function $u^k(x,s^t)$ is strictly concave and upper semicontinuous in x.

B.3: For each K there exists $\delta(K)$ such that for all k, t and s^t $u_t^k(x,s^t) < \delta(K)$, provided $\|x\| < K$.

C.1: For each s^N the set $Y(s^N)$ is a closed convex set in R^N.

C.2: For each s^N

$$\underline{0} \in Y(s^N)$$

C.3: The set $Y(s^N)$ is uniformly bounded,[1/] i.e., there exists a constant d (independent of s^N) such that for each $y \in Y(s^N)$

$$|y| < d$$

($|y|$ denotes the maximum of the absolute values of the coordinates of y).

First we prove the existence of solution of the problem (2.7)-(2.10).

Let H be a space of functions on S^N with values in $R^{n \times N}$. A point of H is a set of q-dimensional random vectors $\{x_m^i(s^N), i = 1,2,\ldots,n;\ m = 1,2,\ldots,N\}$ such that $x_m^i(s^N)$ is $\bar{F}^N$-measurable, where the bar over a σ-field means the completion of the σ-field with respect to P.

Consider a subset Q in H specified by the following conditions:

1.a: $x_m^k(s^N)$ is a $\bar{F}^t$-measureable function of s^m (i.e. x_m^k does not depend on $s_{m+1}, s_{m+2}, \ldots, s_N$).

1.b: $(x_1^k,(s^1), x_2^k(s^2), \ldots, x_N^k(s^N)) \in X^k(s^N)$ for P-almost all s^N.

1.c: $\left(\sum_{k=1}^{n} x_1^k(s^1), \sum_{k=1}^{n} x_2^k(s^2), \ldots, \sum_{k=1}^{n} x_N^k(s^N)\right) \in Y(s^N)$ for P-almost all s^N.

Lemma 1. The set Q is convex uniformly bounded and almost surely closed. The latter means that $z(s^N) \in Q(s^N)$ for almost all s^N for each sequence $z_k \in Q$ such that

$$z_k \to z \text{ a.s. } .$$

Proof: Convexity of Q follows from A.1 and C.1. Let c and d be the vector and the constant from the conditions A.3 and C.3, and $\alpha = |c|$. Then 1.b and 1.c implies that for every

$$\{x_m^i(s^m), i = 1,2,\ldots,n;\ m = 1,2,\ldots,N\} \in Q$$

(3.1) $$x_m^i(s^m) > -\alpha\, \underline{1}$$

(3.2) $$x_m^i(s^m) < [d + (n-1)\alpha]\underline{1}$$

where $\underline{1}$ indicates the q-dimensional vector whose coordinates are equal to $\underline{1}$. Inequalities (3.1) and (3.2) imply uniform boundedness of Q.

Suppose that $z^k(s^N) = \{{}^k x_m^i, i = 1,\ldots,n;\ m = 1,\ldots,N\}$ converges to $z(s^N) = \{x_m^i(s^m), i = 1,\ldots,n;\ m = 1,\ldots,N\}$ as $k \to \infty$ for almost all s^N. Condition 1.a holds automatically for z. Since X^k is closed z satisfies 1.b. Since Y is closed z satisfies 1.c.

Define a functional U on Q by the formula

$$U(z) = E\{ \sum_{k=1}^{n} \sum_{t=1}^{N} u(x_t^k(s^t),s^t)\} \quad ,$$

here

$$z = \{x_m^i(s^m), i = 1,2,\ldots,n;\ m = 1,2,\ldots,N\} \in Q$$

<u>Lemma 2.</u> The functional U is strictly concave, bounded from above and upper semicontinuous with respect to a.s. convergence. The latter means that if $z^k \to z$ a.s. then $U(z) > \limsup U(z^k)$.

<u>Proof.</u> Let $z = \{x_m^i(s^m), i = 1,\ldots,n;\ m = 1,\ldots,N\} \in Q$. By Lemma 1 there exists K such that

$$|x_m^i(s^m)| < K$$

Due to B.3

$$u_m^i(x_m^i(s^m),s^m) < \delta(K)$$

whence

$$U(z) < nN\delta(K)$$

Because, by virtue of B.2, u_m^i is strictly concave, then for each $0 < \alpha < 1$

$$u_m^i(\alpha x + (1-\alpha)y, s^m) > \alpha\, u_m^i(x,s^m) + (1-\alpha)u_m^i(y,s^m) \quad . \tag{3.3}$$

Assuming $x = x(s^m)$ and $y = y(s^m)$ and taking mathematical expectation of both parts of (3.3), we get that U is strictly concave.

Similar arguments show that B.2 implies U to be upper semicontinuous and the lemma is proved.

Lemmas 1 and 2 show that U and Q satisfy the conditions of Theorem 5 of Appendix III in Arkin and Evstigneev [1979], therefore there exists $\hat{z} = \{\hat{x}_t^i(s^t),\ i = 1,2,\ldots,n;\ t = 1,\ldots,N\} \in Q$ such that

$$U(\hat{z}) = \max_{z \in Q} U(z) \quad .$$

Since U is strictly concave such $\hat{z}$ is unique.

Note that the set of random vectors $\{\hat{x}_t^i(s^t)\}$ is the solution of (2.7)-(2.10). Next, we show that $\hat{x}_t^i$ can be obtained by individual optimizations if the prices and taxation are properly chosen.

<u>Theorem.</u> There exists a family of random vectors $p_t(s^t)$, $t = 1,2,\ldots,N$ and a family of random variables $\alpha_t^i(s^t)$, $t = 1,2,\ldots,N$; $i = 1,2,\ldots n$ such that for each i and t $\hat{x}_t^i(s^t)$ is the solution of (2.2)-(2.4)

<u>Proof 1:</u> Fix t and s^t. Let

$$\hat{y} = \sum_{i=1}^{n} \hat{x}_t^i(s^t) \quad .$$

Let Z be the set of all product-vectors y such that

<u>2.a</u>: There exist $x^1, x^2, \ldots, x^n$ such that

$$x^i \in X_t^i(s^t \mid \hat{x}_1^i(s^1), \hat{x}_2^i(s^2), \ldots, \hat{x}_{t-1}^i(s^{t-1}))$$

$$\sum_{i=1}^{n} x^i = y$$

<u>2.b</u>: $$\sum_{i=1}^{n} u_t^i(\hat{x}_t^i(s^t), s^t) < \sum_{i=1}^{n} u_t^i(x^i, s^t)$$

By virtue of A.1 and B.2 the set Z is a convex set in $\mathbb{R}$, and the condition 2.b implies $\hat{y} \notin Z$.

Therefore there exists a vector $p_t(s^t) \in \mathbb{R}$ such that for each $y \in Z$

(3.4) $$p_t(s^t)y > p_t(s^t)\hat{y}$$

(see Rockafellar [1970], Chapter 3; if Z is empty then $p_t(s^t)$ may be any vector). Put

$$\alpha_t^i(s^t) = p_t(s^t)\hat{x}_t^i(s^t) \quad .$$

<u>Proof 2:</u> Next we show that the above defined p_t and α_t^i are the prices and taxation we are looking for.

Suppose that there exists k such that the solution $\tilde{x}$ of (2.2)-(2.4) differs from $\hat{x}_t^k(s^t)$. Because the conditions (2.3), (2.4) define a convex set and u_t^k is strictly concave then the solution of (2.2)-(2.4) is unique. On the other hand $\hat{x}_t^k(s^t)$ satisfies (2.3) and (2.4), therefore

(3.5) $$u_t^k(\tilde{x}, s^t) > u_t^k(\hat{x}_t^k(s^t), s^t)$$

Let

$$z = \tilde{x}_t^1(s^t) + \hat{x}_t^k(s^t) + \dots + \hat{x}_t^{k-1}(s^t) + \tilde{x} + \hat{x}_t^{k+1}(s^t) + \dots + \hat{x}_t^n(s^t)$$

Inequality (3.5) implies $z \in Z$. On the other hand

$$p_t(s^t)z < \sum_{k=1}^{n} \alpha_t^k(s^t) = p_t(s^t)\hat{y}$$

and that contradicts (3.4).

Remark 1. Using proper theorems of measurable selection, it is possible to show that $p_t(s^t)$ and $\alpha_t^k(s^t)$ can be chosen as measurable functions of s^t. However, measurability of p's and α's is not essential in the formulation of equilibrium, because p's and α's are not involved in mathematical expectations.

The model, in which S is finite and (2.3) is replaced by an expression with mathematical expectation in the left-hand side was considered by Debreu in Theory of Value [1976].

Remark 2. The same arguments show the existence of equilibrium if $\hat{x}_t^i(s^t)$ is any Pareto-optimal system of product-vectors.

Footnotes

1/ Primary resources are included in constraints embodied in Y.

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