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Tradeable Emission Quotas for CO_2: Quotas on Use of Carbon or on Production of Carbon?

by

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TRADEABLE EMISSION QUOTAS FOR CO_2:

QUOTAS ON USE OF CARBON OR ON PRODUCTION OF CARBON?

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Abstract
As long as all countries are assumed to participate in an agreement to reduce CO_2 emissions, quotas on use and quotas on production of fossil fuels have identical economic consequences. This is no longer true if there is limited participation in the international agreement. In particular, it is shown that the international price of carbon is higher when quotas are on production than when quotas are on the use of carbon. It is also shown that quotas only on use or only on production of carbon generally are inferior to policies directed towards both the use and production of carbon. If net imports of fossil fuels to the cooperating countries are sufficiently close to zero, it is optimal for the cooperating countries to restrict both their use and their production of carbon. In this case it is also optimal for the cooperating countries to reduce carbon supply in the non-cooperating countries, through buying fossil fuel deposits, if they have this option.

1. Introduction

Tradeable quotas (or emission permits) for CO_2 emissions are often proposed as a method of achieving a cost efficient allocation of emissions between countries, cf. e.g. Grubb (1989), Hoel (1991a,b). In practise, emissions of CO_2 are not directly observable. Unlike most emissions of gases to the atmosphere, CO_2 emissions are very closely and directly linked to the use of a specific product, namely fossil fuels. Instead of quotas on emissions of CO_2, one can therefore have quotas on the use of fossil fuels. However, except for the small changes in inventories, the use of fossil fuels is equal to the production of fossil fuels. As an alternative to limiting CO_2 emissions through quotas on the use of fossil fuels, one could therefore have quotas on the production of fossil fuels.

As long as all countries are assumed to participate in an agreement to reduce CO_2 emissions, quotas on use and quotas on production of fossil fuels have identical economic consequences. To see this, consider Figure 1. In this figure, fossil fuels are treated as an aggregate variable (carbon), with x as output and p as price. The carbon market is assumed to be competitive, and the demand and supply functions are denoted by d(p) and s(p), respectively. Without any type of regulation, the competitive equilibrium is given by (p°,x°).

Assume that there is an agreement to reduce the quantity of carbon (used and produced) from x° to x^*. With quotas on the use of carbon, which henceforth will be called demand regulation, the effective demand curve is changed from d(p) to $ABCx^*$ in Figure 1. The supply curve is in this case unchanged, and the new market price for carbon is p^D. However, at the quantity x^* consumers are willing to pay p^S, the difference between p^S and p^D is therefore the equilibirum price of carbon quotas. The total price of carbon for consumers (including the quota price) is thus p^S, while producers receive p^D.

If quotas instead are on the production of carbon, which henceforth will be called supply regulation, the demand curve is unaffected, i.e. it is given by d(p) in this case. However, in this case the effective supply curve is changed from s(p) to DCBE in Figure 1. The market price for carbon is thus p^S in this case. Producers are willing to produce the quantity x* for the price p^D, the difference between p^S and p^D is therfore the price the producers must pay for their quotas. Just as in the case of demand regulation, the price consumers pay is p^S, while the net price producers receive (after subtracting the cost of quotas) is p^D.

It is thus clear that it makes no difference whether quotas are on use or on production. In both cases the total cost of using carbon is p^S, while the producers receive p^D pr. unit of produced carbon. The price pr. quota is in both cases p^S-p^D, and the total number of quotas is the same in both cases (since production is equal to use, ignoring inventory changes). As long as the distribution of quotas among agents is the same in both cases, demand regulation and supply regulation have identical effects on the economy. In the Appendix, this result is generalized to to a non-cooperative market with several types of fossil fuels.

So far, no climate agreement between countries exists. It is likely that some form of agreement will be reached during the next decade. However, at least initially, it is very unlikely that all countries will participate in such an agreement. Limited participation in the agreement has important consequences: When the participating countries reduce their demand for fossil fuels, international fuel prices will rise. This gives the non-participating countries an incentive to increase their use of fossil fuels, thus partly offsetting the reduced emissions from the participating countries. Pezzey (1991) has done an analysis showing that this effect might be quite strong. It is therefore of interest to see if there are ways to avoid or reduce this offsetting emission increase from non-cooperating countries.

One way of avoiding increased emissions from non-cooperating countries is to reduce the supply of fossil of fossil fuels from the non-cooperating countries. This has been studied by Bohm (1991), who assumes that the cooperating countries can buy or lease fuel deposits in the non-cooperating countries. In sections 2 and 3 of the present analysis this option is ignored. Instead, it is assumed that the cooperating countries themselves have a positive supply of fossil fuels. This supply can therefore be affected by e.g. tradeable quotas on the production of fossil fuels within the cooperating countries. In section 2 this type of quotas is compared with quotas on the use of fossil fuels. One of the results is that without more detailed information on demand and supply functions, it is not possible to know whether demand regulation or supply regulation is best for the cooperating countries.

Section 3 considers the optimal choice of supply and demand regulations in more detail. It is shown that there are plausible cases in which it is optimal to have quotas both on use and production of carbon.

Section 4 introduces the option that the cooperating countries can buy or lease fuel deposits in the non-cooperating countries. It is shown that such a policy is optimal if and only if it is optimal to simultaneously restrict supply among the cooperating countries (through the use of quotas or other policy instruments). It is also shown that supply should in a sense (made precise in proposition 11) be restricted more within the cooperating countries than in the non-cooperating countries.

Throughout the paper, two rather restrictive assumptions are used. The first is that the analysis is static. This means that the exhaustible nature of carbon resources is ignored. It also means that we are ignoring the fact that it is not current emissions which matter for the environment, but rather the atmospheric concentration of CO_2 (and other greenhouse gases).

The second restrictive assumption is that the carbon market is treated as one aggregate, competitive market. In reality, there are several (interrelated) markets for different types of fossil fuels, and all of these deviate more or less from perfect competition.

The main results of the paper will probably remain valid even if one relaxes the above assumptions. A more detailed analysis of this question is however a topic for future research.

2. Limited participation in an international climate agreement.

Assume that there are two groups of countries. The first group, denoted by C (for cooperating), cooperates in order to achieve a target level x* for total carbon emissions. The second group, denoted by N (for non-cooperating), uses and produces carbon in accordance with its demand and supply functions without any consideration for the environment. Demand and supply functions for the two groups are denoted by $d_j(p)$ and $s_j(p)$, respectively (j=C,N). As before, aggregate demand and supply are denoted by d(p) (=$d_C(p) + d_N(p)$) and s(p) (=$s_C(p)+s_N(p)$), respectively.

Without any climate policy, the equilibrium price and output level are given by the point (p°, x°) in Figure 2. Assume that the cooperating countries have a target level x* (< x°) for total carbon emissions, which they achieve either through demand regulation or through supply regulation. With demand regulation, they limit their own demand to d_C*, where d_C* is determined by

(1) $$d_C^* + d_N(p^D) = s_C(p^D) + s_N(p^D)$$

(2) $$d_C^* + d_N(p^D) = x^*$$

Given the target x* for total carbon emissions, equations (1) and (2) determine d_C* and the equilibrium price p^D. Figure 2 illustrates this new equilibrium.

Since p^D satisfies $s(p^D)=x^*$ both in Figure 1 and 2, and $s'(p)>0$, we have the following result:

Proposition 1: Under demand regulation, the market price for carbon (p^D) is lower the lower is the target level of carbon emissions (x*) is. However, this price is independent of how large the group of cooperating countries is.

Instead of regulating their demand, the cooperating countries could limit their supply to s_C*, where s_C* is determined by

(3) $$d_C(p^S) + d_N(p^S) = s_C^* + s_N(p^S)$$

(4) $$s_C^* + s_N(p^S) = x^*$$

Equations (3) and (4) determine s_C* and the equilibrium price p^S for the case of supply regulation. The equilibrium is illustrated in Figure 2.

In this case p^S satisfies $d(p^S)=x^*$ both in Figure 1 and 2, and since $d'(p)<0$ we have the following result:

<u>Proposition 2</u>: **Under supply regulation, the market price for carbon (p) is higher the lower is the target level of carbon emissions (x*). However, this price is independent on how large the group of cooperating countries is.**

The prices p^D and p^S are the international market prices for carbon under demand and supply regulative, respectively. From Figure 2 we immediately have the following result:

<u>Proposition 3</u>: **The international price of carbon is higher under supply regulation than under demand regulation.**

This proposition leads to our next result:

<u>Proposition 4</u>: **If the non-cooperating countries are net exporters of carbon in the case of demand regulation, they are better off with supply regulation than with demand regulation. If the non-cooperating countries are net importers of carbon in the case of supply regulation, they are better off with demand regulation than with supply regulation.**

<u>Proof</u>: If the non-cooperating countries are net exporters of carbon in the case of demand regulation, they must also be net exporters of carbon in the case of supply regulation, since $p^S > p^D$, $s_N'(p) > 0$ and $d_N'(p) < 0$. Being net exporters under both types of regulations, they are clearly best off under the regulation type which gives the highest price, which is supply regulation (cf. Proposition 3). A similar argument holds for the case in which the non-cooperating countries are net importers of carbon under supply regulation.

Q.E.D.

Under demand regulation, the quota price q must be so high that consumers are on their demand curve, i.e.

(5) $$d_C(p^D+q^D)=d_C^*$$

Using (2) - (4), it follows from (5) that

(6) $$d_C(p^D+q^D)+d_N(p^D)=d_C(p^S)+d_N(p^S)$$

or

(7) $$d_C(p^S)-d_C(p^D+q^D)=d_N(p^D)-d_N(p^S)$$

Since $p^S>p^D$ and $d_N'(p)<0$, the r.h.s. of (7) is positive. Equation (7) therefore implies that $p^D+q^D>p^S$ (since $d_C'(p)<0$), i.e.

(8) $$q^D>p^S-p^D$$

A similar reasoning for the case of supply regulation gives

(9) $$s_C(p^D)-s_C(p^S-q^s)=s_N(p^S)-s_N(p^D)$$

which implies $p^S-q^S<p^D$, i.e.

(10) $$q^S > p^S - p^D$$

We thus have the following result:

Proposition 5: Under both types of regulation, the quota price is higher than the difference between the market price of carbon under supply regulation and under demand regulation.

Notice that proposition 5 holds in the strict sence (i.e. the quota price is strictly higher...) only when there are some non-cooperative countries. Under full cooperation, the quota price is equal to p -p under both types of regulations.

Consider equation (7). If a country is moved from the cooperating to the non-cooperating group, the r.h.s. of (7) goes up, while the l.h.s. goes down (for a given q^D). To restore the equality, q^D must go up. A similar reasoning on equation (9) reveals that q^S must go up if a country is moved from the cooperating to the non-cooperating group. We thus have the following result:

Proposition 6: Under both types of regulation, the quota price goes up if a country moves from the cooperating to the non-cooperating group.

Since the quota price is equal to p^S-p^D under both types of regulation if there is full cooperation, proposition 1, 2 and 5 give the following result:

Proposition 7: In the cooperating countries, the price of using carbon (including the price of quotas) is higher under demand regulation than it is under supply regulation, while the price received for producing carbon (after subtracting the price of quotas) is lower under supply regulation than it is under demand regulation.

Without more detailed information on demand and supply functions, it is not possible to know whether demand regulation or supply regulation is best for the cooperating countries. It follows from proposition 7 that as users of carbon, the cooperating countries are better off with supply regulation than with demand regulation. On the other hand, proposition 7 also implies that as producers, the cooperating countries are better off with demand regulation than with supply regulation. Moreover, in addition to the user and producer role, the cooperating countries receive quotas which have a value. Both amount of quotas (e.g. measured in tons of carbon) and the value of each quota differ between demand and supply regulation. Even if the distribution of quotas among the cooperating countries is the same under the two types of regulation, the countries will generally get different "quota incomes" under the two types of regulation. The cooperating countries are both users of carbon, producers of carbon, and receivers of quotas. It follows from the discussion above that there is no unambigous answer to the question of which type of regulation is best for the cooperating countries. However, other things equal, a move from demand to supply regulation (with unchanged distribution of quotas among the cooperating countries) will give a relative increase of welfare to those of the participating countries which have high net imports (or low net exports) of carbon from those which have low net imports (or high net exports) of carbon.

In order to get a better understanding of when demand regulation is best and when supply regulation is best, the next section considers the optimal mix of demand and supply restrictions in the cooperating countries.

3. The optimal mix of demand and supply restrictions

Denote production and use of carbon in the cooperating countries by x and y, respectively. The utility function for use of carbon is given by u(y) (corresponding to the demand function $d_C(p)$ derived from $u'(y)=p$), and the cost function for production of carbon is c(x) (corresponding to the demand function $s_C(p)$ derived from $c'(x)=p$). It is assumed that $u'>0$, $u''<0$, $c'>0$ and $c''>0$.

As before, supply and demand functions for the non-cooperating countries are given by $s_N(p)$ and $d_N(p)$, respectively.

Market equilibrium implies that

(11)
$$y+d_N(p)=x+s_N(p)$$

which gives

(12)
$$p=p(y-x)$$

where

(13)
$$p'=\frac{1}{s_N'-d_N'}>0$$

The optimal choice of x and y for the cooperationg countries is the solution to

(14)
$$\begin{aligned} \max \quad & u(y)-c(x)-p(y-x)\cdot(y-x) \\ s.t. \quad & y+d_N(p)\leq x^* \end{aligned}$$

The Lagrangian to this problem is

(15) $$L=u(y)-c(x)-p(y-x)\cdot(y-x)+\lambda[x^{*}-y-d_N(p)]$$

and the first order conditions are (after inserting from (13))

(16) $$u'(y)=p+(y-x)\cdot p'+\lambda\frac{s_N'}{s_N'-d_N'}$$

(17) $$c'(x)=p+(y-x)\cdot p'+\lambda\frac{d_N'}{s_N'-d_N'}$$

Without any regulation of use or production of carbon, consumers and producers would choose

(18) $$u'(y)=p$$

(19) $$c'(x)=p$$

Consider first the case with no climate policy. In this case the shadow price λ on the emission constraint is zero, and it is clear from (16) and (17) that users and producers should face the same price of carbon. This price is equal to the international price of carbon (p) plus an "optimal tariff" term. The latter term is positive if the cooperating countries are not importers of carbon. The most obvious instrument to raise the domestic price from p to p+(y-x)p' for both users and producers is to have an import tariff equal to (y-x)p'. Alternatively, one could tax consumption and subsidize production, both at the rate (y-x)p'. Instead of the consumption tax one could use tradeable quotas for the consumption of carbon. In principle, a subsidy on production could be replaced by a tradeable quota which requires a specific (minimum) production. Owners of such quotas would have to pay other producers to take over this production obligation if they did not produce the required amount themselves. The term (y-x)p' would in this case represent the payment a producer would receive as a compensation for taking over the production obligation.

If the cooperating countries are net exporters (x>y), the optimal tariff term (y-x)p' in (16) and (17) is negative. The most obvious instrument to reduce the price from p to p+(y-x)p' for both users and producers of carbon is in this case an export tariff equal to (x-y)p'. The discussion above on taxes, subsidies and quotas, with the appropriate adjustments, applies also to the present case.

When the emission constraint in the maximization problem (14) is binding, λ is positive. In this case the third term in the r.h.s. of (16) is positive, implying that consumption of carbon should cost more than the international price of carbon plus the optimal tariff (the latter being positive or negative depending on y>x or x>y). The third term in the r.h.s. of (17) is negative, implying that production of carbon should be paid less than the international price of carbon plus the optimal tariff.

From the discussion above, it is thus clear that the following two propositions follow from (16) and (17):

Proposition 8: Assume that use and production of carbon in the cooperating countries are equal, or that these countries are using an optimal import or export tariff. Then it is optimal for the cooperating countries to restrict both their use and their production of carbon. The optimal mix of these two types of restrictions is such that the ratio between the shadow price of the demand and supply

restriction is equal to the ratio between the supply and demand derivative for the group of non-cooperating countries.

Proposition 9: If the group of cooperating countries is a net importer of carbon, and an optimal import tariff (or similar instruments) is not used, it is optimal to restrict the use of carbon. Whether the production of carbon should be restricted or encouraged in this case depends on the structure of the economy. If the group of cooperating countries is a net exporter of carbon, and an optimal export tariff (or similar instruments) is not used, it is optimal to restrict the production of carbon. Whether use of carbon should be restricted or encouraged in this case depends on the structure of the economy.

If use of carbon and/or production is restricted, this may be done through the use of tradeable quotas on use and/or production of carbon. It follows from Propositions 8 and 9 that there are circumstances in which it is optimal to have quotas both on use and production of carbon.

In section 2, a comparison was given between regulation only of demand versus regulation only of supply. It is clear from Propositions 8 and 9 that both of these regulatory systems usually will be inferior to policies directed towards both the use and the production of carbon.

If one has to choose between regulation only of use of carbon or only of production of carbon, it follows from Propositions 8 and 9 that there is no unambiguous answer to which of these regulatory systems is best. From Propositions 8 and 9, it also follows that the relative merit of demand regulation compared to supply regulation is higher the higher are the net imports (or the lower are the net exports) of the cooperating countries, the lower is the carbon demand elasticity of the non-cooperative countries (measured positively) and the higher is the carbon supply elasticity of the non-cooperative countries.

4. Supply reductions in non-cooperating countries.

As mentioned in section 2, Bohm (1991) has analyzed the case in which cooperating countries can buy (or lease) fuel deposits in the non-cooperating countries. In this section we discuss whether such a policy is an alternative or a complement to the policy of restricting own production of carbon.

The notation from section 3 is used also in the present section, with one exception: $s_N(p)$ now denotes potential supply, i.e. what the supply in the non-cooperating countries would have been (at price p) without any purchase of fuel deposits by the cooperating countries. Actual supply is $s_N(p)$-z, where z is the amount of potential carbon supply which is bought by the cooperating countries, but not actually produced.

To understand the meaning of $s_N(p)$ and z in our static framework, it is useful to imagine that supply is an aggregate of many small producers, each with a constant unit production cost and a capacity limit. Unit costs differ between producers, so that the aggregate supply function is a step function as illustrated in Figure 3. This may be approximated by the marginal cost function $c_N'(x_N)$ in Figure 4, where x_N is total production in the non-cooperating countries. The cooperating countries buy the capacity z from the non-cooperating producers with the highest unit costs, so that supply is reduced from $s_N(p)$ to $s_N(p)-z = s_N(p-q)$, cf. Figure 4. To obtain control over this capacity, the cooperating countries must pay q per unit of capacity, where q is equal to the rent of the marginal producer, i.e. $q = p - c_N'(p)-z)$. Since the supply function is the inverse of the marginal cost function, this may be rewritten as

$$s_N(p-q)=s_N(p)-z \tag{20}$$

The balance equation (11) is now changed to

(21)
$$y+d_N(p)=x+s_N(p)-z$$

which gives

(22)
$$p=p(y-x+z)$$

Equation (13) (i.e. $p' = 1/(s_N'-d_N') > 0$) remains valid also in the present case.

Inserting (22) into (20) and differentiating gives

(23)
$$\begin{aligned}\frac{\partial q}{\partial y} &= [1-\frac{s_N'(p)}{s_N'(p-q)}]p' \\ \frac{\partial q}{\partial x} &= -\frac{\partial q}{\partial y} \\ \frac{\partial q}{\partial z} &= \frac{\partial q}{\partial y}+\frac{1}{s_N'(p-q)}\end{aligned}$$

To simplify our analysis, we assume $s_N = 0$, i.e. that the aggregate potential supply curve in the non-cooperating countries is linear. In this case q depends only on z, and the function q(z) has the following properties[1]

(24)
$$\begin{aligned}q(0) &= 0 \\ q'(z) &= \frac{1}{s_N'(p-q)} > 0\end{aligned}$$

The maximization problem (14) is now changed to

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[1] Notice that q=0 for z=0 even if $s_N'' \neq 0$, cf. Figure 2.

(25)
$$\max \quad u(y)-c(x)-p(y-x+z)\cdot(y-x)$$
$$s.t. \quad y+d_N(p) \le x^*$$
$$z \ge 0$$

In this maximization problem the choice variables are x, y and z. As in section 2, we ignore the possibilities of corner solutions with x=0 or y=0.

Straightforward calculations reveal that (16) and (17) are valid also in the present case. In addition, we have

(26)
$$-q-zq'-(y-x)p'-\lambda d_N'p' \le 0$$

where z=0 if the strict inequality applies. Adding (17) and (26) and using (13) gives

(27)
$$c'(x) \ge p-(q+zq')$$

where > implies x=0. From (27) we obtain the following proposition:

<u>Proposition 10:</u> It is optimal to reduce supply in the non-cooperating countries if and only if the international carbon price exceeds the marginal cost of domestic carbon production in equilibrium (i.e. c'(x)<p).

<u>Proof:</u>

Combining c'(x) <p with (27) gives q+zq'>0, which implies z>0 from (24). If z>0, then (27) gives c'(x)=p-(q+zq'), which is larger than p due to (24).

Q.E.D.

If c'(x)<p in equilibrium, we have some kind of supply restrictions among the cooperating countries. Proposition 10 therefore implies that a policy of reducing supply in non-cooperative countries is complementary to a policy of restricting supply within the cooperating countries.

When z>0, the variables x, y and z are determined by (16), (17) and (27) (with equality). From (17) and (27) we see that

$$c_N'(x_N) - c'(x) = zq' \qquad (28)$$

We thus have the following proposition:

Proposition 11: When the optimal policy implies supply reductions in the non-cooperating countries (i.e. z > 0), the marginal cost of carbon production in the non-cooperating countries exceeds the corresponding marginal cost in the cooperating countries.

Loosely speaking, this proposition says that supply should be restricted more within the cooperating countries than in the non-cooperating countries.

Appendix. The equivalence between quotas on use and on production when all agents are covered by the quota system.

Consider a market which is characterized by a Cournot oligopoly with a competitive fringe. There are N types of fossil fuels, all of which are measured in terms of their carbon content. Demand for type j fuel is $d_j(p_1,...p_N)$, where the p-vector is the price vector consumers face (including the price of quotas if there are quotas on the use of fossil fuels). Fringe supply of type j fuel is $s_j(p_1,...p_N)$, where the p vector is the price producers receive (after subtracting the price of quotas if there are quotas on the production of of fossil fuels). Since fuels are measured by their carbon content, the difference between the consumer price pj and the producer price pj must be the same for all fuel types. Denoting this differnce by q, we thus have $q = p^S - p^D$. Notice that q is the is the quota price, whether quotas are on use or production of carbon.

The output of fuel type j by oligpolist k is x_j^k. Market equilibrium is thus characterized by

(A.1) $$\Sigma_k x_i^k + s_i(p_1,...,p_N) = d_i(p_1+q,...,p_N+q)$$

This equilibrium condition gives the N prices p_j as functions of the KN oligopoly outputs x_j^k and the quota price q.

Each oligopolist wishes to maximize its profits π^k, given by

(A.2) $$\pi^k = \Sigma p_i x_i^k - c^k(x_1^k,...,x_N^k)$$

where $c^k(x_1^k,...x_N^k)$ is the cost function for oligopolist nr. k.

A Cournot equilibrium without any demand or supply regulation is characterized by each oligopolist choosing its x^k-vector so that π^k given by (A.2) is maximized, taking all other x^h-vectors as given and taking account of the relationship (A.1) (with q = 0) determining prices.

With demand regulation, there is an additional constraint

$$d_i(p_1+q,\dots,p_N+q)\leq x^* \tag{A.3}$$

and q is no longer zero (provided the constraint (A.3) is binding). In this case the Cournot equilibrium is characterized by each oligopolist choosing its x^k-vector so that (A.2) is maximized, taking all other x^h-vectors as given and taking account of the relationships (A.1) and (A.3) (with equality) determining q and the p-vector.

If one instead of demand regulation has quotas on production, (A.3) is substituted by

$$\Sigma_i\Sigma_k x_i^k+\Sigma_i s_i(p_1,\dots,p_N)\leq x^* \tag{A.4}$$

However, profit maximization with (A.1) and (A.3) as constraints is equivalent to profit maximization with (A.1) and (A.4) as constraints. There is therefore no difference between demand regulation and supply regulation.

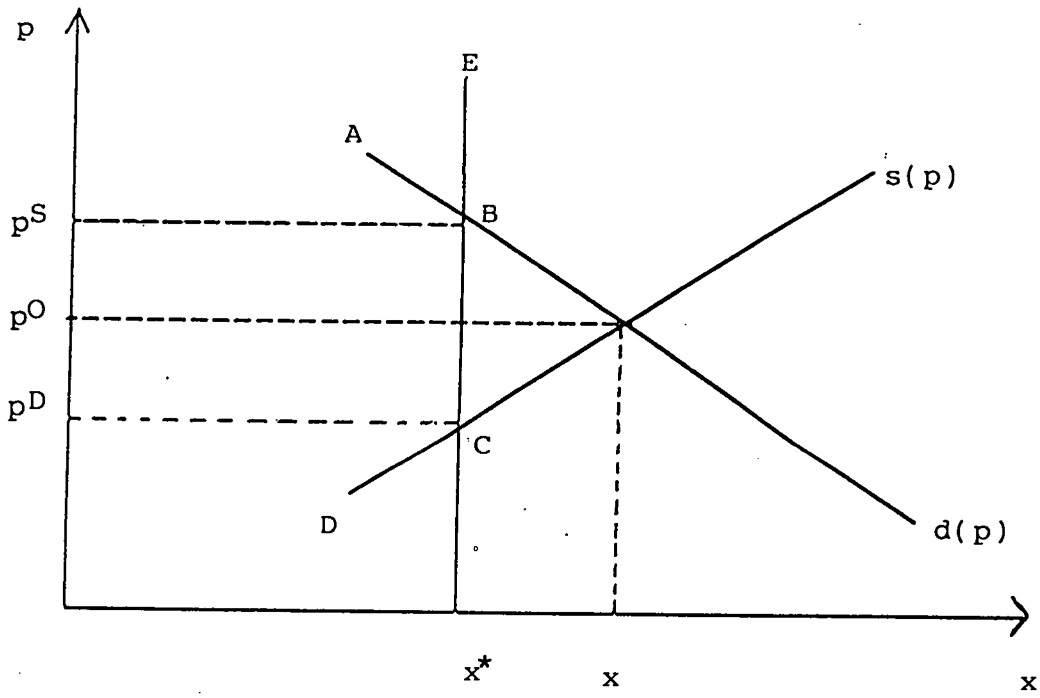

FIGURE 1

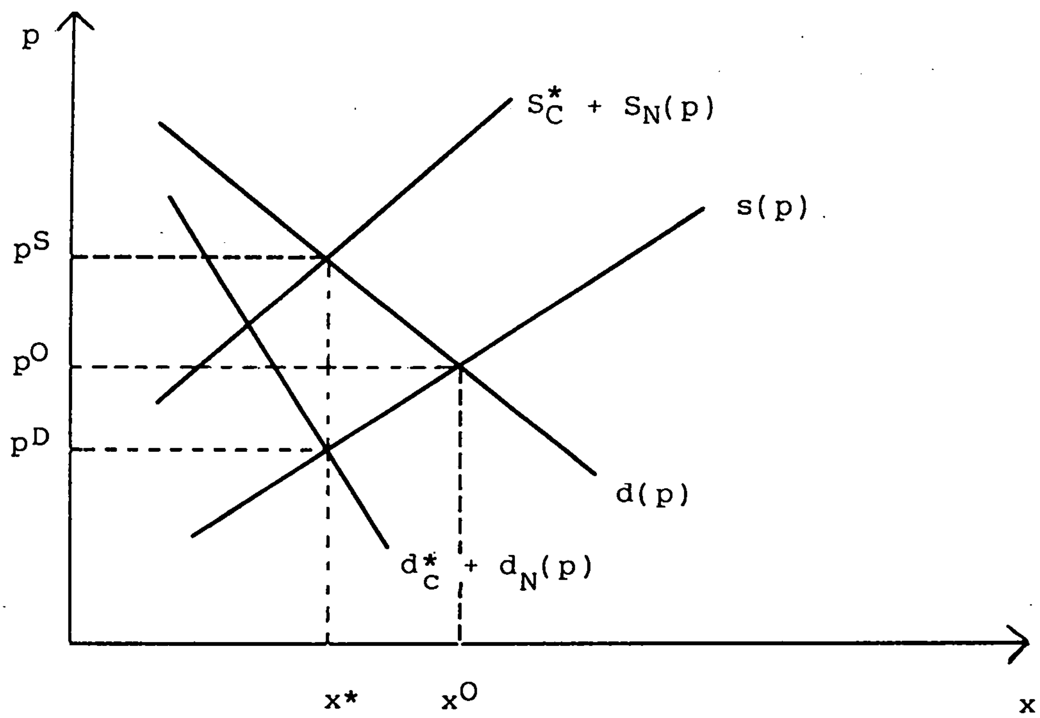

FIGURE 2

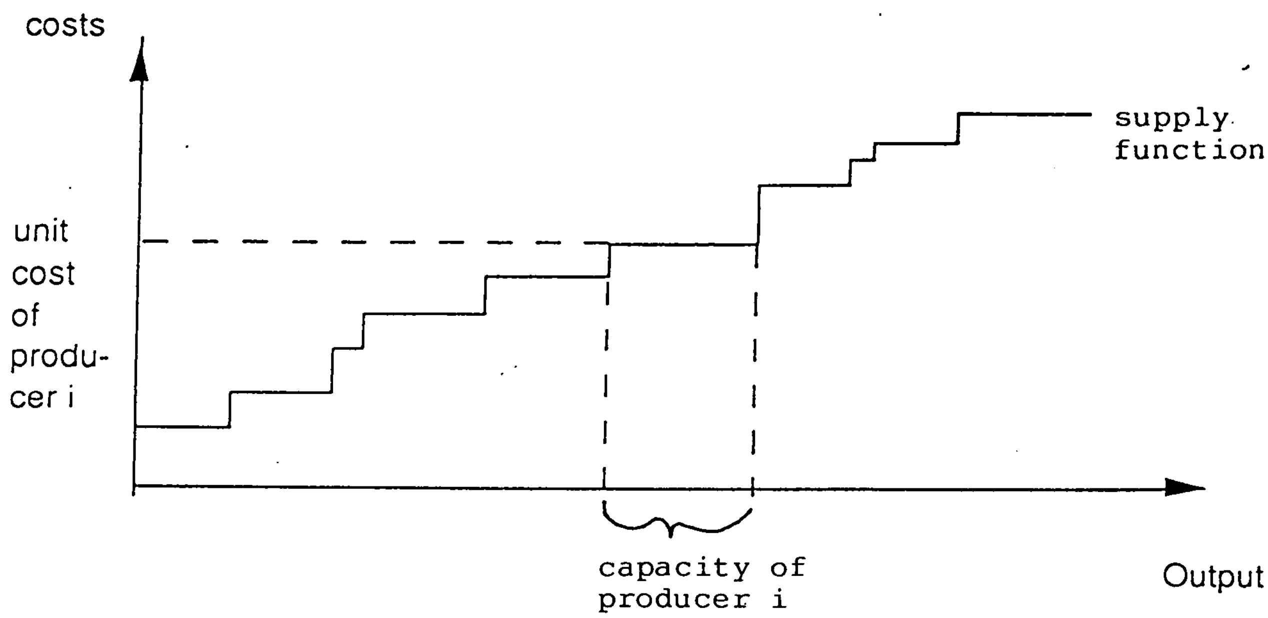

FIGURE 3

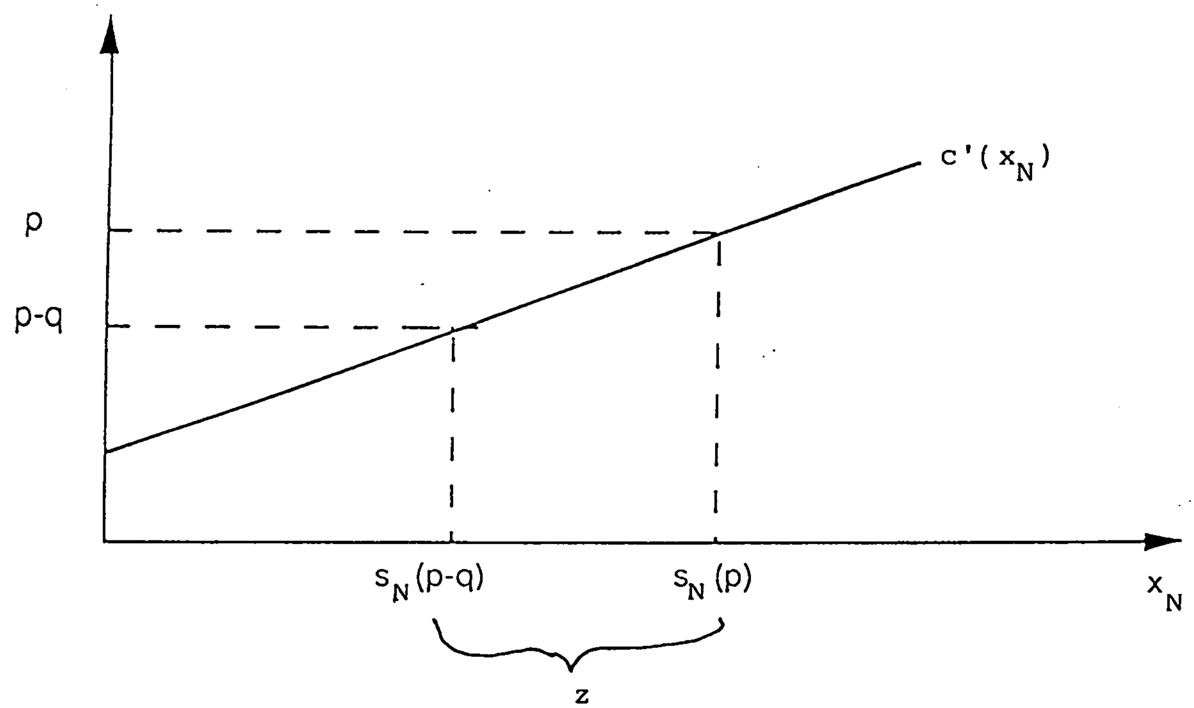

FIGURE 4

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