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A Note on Market Power in an Emission Permits Market with Banking

Matti Liski and Juan-Pablo Montero*

April 22, 2003

Abstract

In this paper, we investigate the effect of market power on the equilibrium path of an emission permits market in which firms can bank current permits for use in later periods. In particular, we study the market equilibrium for a large (potentially dominant) firm and a competitive fringe with rational expectations. Rather than providing a full description of the equilibrium solution for all combinations of permits allocations and cost structures, we provide a characterization of the equilibrium solution for a few illustrative cases. For example, we find that if the large firm enjoys a dominant position in the after-banking market, it can always extend this dominant position to the market during the banking period regardless of the allocation of the stock (bank) of permits.

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1 Introduction

Emission permits trading usually refers to trades across space in the same period of time, but it can also refer to trades through time, typically by banking, i.e., the possibility of carrying over unused permits from one period for use in later periods.[1] Over the past decade, this latter dimension of emission permits trading has drawn increasing attention in the literature and proposals to decrease emission caps over time suggest a particular larger role for banking in the future.[2] A salient example is the US Acid Rain Program, where banking has been a major form of emissions trading (Ellerman et al, 2000; Ellerman and Montero, 2002). During the first five years of the program constituting Phase I, 1995-99, only 26.4 million of the 38.1 million permits (or allowances) distributed were used to cover emissions. The remaining 11.65 million allowances (30% of all the allowances distributed) were banked to be used during Phase II.

Several authors have studied the theoretical properties of intertemporal trading (Rubin, 1996; Cronshaw and Kruse, 1996; Schennach, 2000), but there is little work looking at the effect of market power on the equilibrium path. Because the evolution of a permits bank is closely related to the evolution of an exhaustible resource stock,[3] in this paper we draw upon both the literature on permits markets and the literature on exhaustible resources to analyze whether and how a large (dominant) firm can affect the market equilibrium path. We consider the possibility of market power both during and after the banking period. We find that if the large firm is able to exercise market power in the after-banking market, as described by Hahn (1985), then it is also able to manipulate the market during the banking period regardless of the permits allocation during the banking period.

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[1] Borrowing of permits from future vintages could also be included (and may be efficient to do so), but it has attracted much less attention than banking.

[2] An effective policy for reducing atmospheric greenhouse gas concentrations would likely include emission caps that would become more stringent over time.

[3] There are important differences though. First, the permits market still remains after the permits bank has been exhausted while the market for a typical exhaustible resource vanish after the total stock has been consumed. Second, extraction costs for permits are zero while they are generally positive for a typical exhautible resource. In addition, the demand for permits corresponds to a derived demand from the same firms that hold the permits while the demand for a typical exhaustible resource comes from a third party.

The rest of the paper is organized as follows. In Section 2, we present the model and derive the equilibrium path (i.e., price and quantity paths) for a competitive market. In Section 3, we study the evolution of prices and quantities for a market composed of large firm and a competitive fringe with rational expectations. Final remarks are in Section 4.

2 The model

Consider an industry with a large number N of heterogenous plants whose emissions are regulated by a tradeable permits program with banking (a firm may own one or several plants). The regulator allocates a total of $A(t) = \sum_{i=1}^{N} a_i(t)$ allowances (or permits) in period t, where $a_i(t)$ is plant i's allocation at t (we will use capital letters for industry or group-level variables and small letters for plant-level variables). For (aggregate) banking to actually happen permits allocations must decrease over time (at least at a rate higher than the discount rate for some period of time). To follow the design of the US Acid Rain Program, we assume that during the first T_0 periods of the program the total number of permits allocated in each period is A_H and that thereafter is A_L, with $A_H \gg A_L$.[4]

Plant i's unrestricted or counterfactual emissions (i.e., emissions that would have been observed in the absence of the permits program) are denoted by u_i and its abatement costs by $c_i(q_i(t))$, where $q_i(t)$ are emissions reduced at period t. Thus, plant i's emissions at t are $e_i(t) = u_i - q_i(t)$. An efficient market solves the following infinite horizon intertemporal minimization problem (Rubin, 1996; Schennach, 2000)

$$\min \int_0^{\infty} \left(\sum_{i=1}^{N} c_i(q_i(t)) \right) \mathrm{e}^{-rt} dt \tag{1}$$

$$\text{s.t. } \dot{B}(t) = A(t) + Q(t) - U \tag{2}$$

$$B(0) = 0, -B(t) \leq 0 \tag{3}$$

where r is the risk-free discount rate, $B(t)$ is the stock (i.e., bank) of allowances at time t (dots denote time derivatives), $Q(t)$ is aggregate reduction and $U > A_L$ is aggregate

[4] Alternatively one can let $(A_H - A_L)T_0$ be the initial "stock" allocation and A_L the per-period allocation.

counterfactual emissions.

The solution of (1)–(3) can be decomposed as follows. First, there is a static efficiency condition that must hold at all times (even after the bank of permits is exhausted): $c_i'(q_i(t)) = c_j'(q_j(t)) = P(t)$ for all $i \neq j$, where $P(t)$ is the equilibrium price of permits at t. To find the rest of the solution, we use the static efficiency condition to denote the industry least-cost curve by $C(Q(t))$. This implies that $C'(Q(t) = P(t)$. Hence, the Hamiltonian for the problem (1)–(3) can be written as

$$H = C(Q(t))\mathrm{e}^{-rt} + \lambda(A(t) + Q(t) - U) - \phi B(t)$$

where $\lambda(t)$ and $\phi(t)$ the multiplier functions.

Necessary conditions for optimality include satisfaction of (2), (3) and[5]

$$\frac{\partial H}{\partial Q} = C'(Q(t))\mathrm{e}^{-rt} + \lambda(t) = 0 \quad (4)$$

$$\dot{\lambda}(t) = -\frac{\partial H}{\partial B} = \phi(t) \quad (5)$$

$$\phi(t) \geq 0, \;\; \phi(t)B(t) = 0 \quad (6)$$

In addition, taking the derivative of (4) with respect to time yields

$$\frac{d(C'(Q(t))}{dt} - rC(Q(t)) + \phi\mathrm{e}^{rt} = 0 \quad (7)$$

When $B(t) > 0$, $\phi(t) = 0$ and marginal costs $C'(Q(t))$, and hence price $P(t)$, follow the Hotelling's rule and rise at the discount rate r (note that permits are "extracted" at zero cost). Expression (7) is commonly known as the (no) arbitrage condition.

Whether and when firms will bank permits depends upon the allocation of permits, the evolution of marginal cost functions and the discount rate. For example, a significant reduction of the permits allocation in the future, as in the SO_2 program, will result in a banking period of some length $T > T_0$ (to be determined shortly): firms bank permits during some period of time and gradually use them thereafter until the bank expires at

[5] See Kamien and Schwartz (1991).

T. After T, permits trading continues (to equate marginal costs across plants) but total emissions remain constant at A_L.

The full compliance condition establishes the total number of permits allocated during the banking period $[0, T]$ be equal to the accumulated emissions during such period, that is (this condition is equivalent to the exhaustion condition found in the depletable resources literature)

$$(A_H - A_L)T_0 + A_L T = \int_0^T E(t)dt \tag{8}$$

At T the terminal condition $E(T) = A(T)$ must also hold, which is

$$Q(T) = U - A_L \tag{9}$$

Combining (7), (8) and (9) we can solve for T^* (the superscript "*" denotes efficiency), which in turn allows us to compute the efficient price and quantity paths; $P^*(t)$ and $Q^*(t)$, respectively.

A solution for T^* can be obtained if we assume some functional form for $C(Q)$. For example, if we assume that $C'(Q)$ is linear, as found by Ellerman and Montero (2002) for the SO_2 program, the abatement path during the banking period is

$$Q(t) = (U - A_L)\mathrm{e}^{-r(T^* - t)} \tag{10}$$

Replacing (10) into (8) and rearranging we have the following expression that solves for T^*

$$\frac{(A_H - A_L)T_0}{U - A_L} = T^* - \frac{1}{r}\left(1 - \mathrm{e}^{-rT^*}\right) \tag{11}$$

Let us next discuss the effect on the market equilibrium path when a large number of plants are owned by a single firm.

3 Banking with market power

Consider now a permits market with banking in which there is a large and (potentially) dominant firm and a competitive fringe.[6] In its attempt to manipulate the market (i.e., deviate from the efficient or competitive outcome), the dominant firm behaves as a Stackelberg leader knowing that all firms in the fringe have perfect foresight. More specifically, the dominant firm's decision problem is to choose the price path along with its reduction (or emission) path that maximizes the net present value of its profits provided that each firm in the competitive fringe will take such price path as given and that neither its bank nor the fringe's bank can go negative.

Although this problem has been already solved for a typical exhaustible resource under different set of assumptions (Salant, 1976; Gilbert 1978; Newbery, 1982), the proposed solutions do not immediately apply to a permits bank for several reasons. First, extraction costs for permits are zero. Second, costs of storage for permits are zero so speculators (and firms in the fringe) will make sure that prices neither jump nor grow at rate higher than r. This also gives the dominant firm the possibility to buy (or sell) a stock of permits from the fringe and store them for future use at no cost other than the opportunity cost of selling them earlier.

Third, in a permits market the dominant producer can still exercise market power after its stock (i.e., bank) and that of the fringe have been exhausted. So, contrary to what would occur in a typical exhaustible resource market, it may be possible that the dominant firm can still use its strategic position of the end of the banking period to exercise some market power during the banking period even if it does not receive any permits from the stock $(A_H - A_L)T_0$ but only an allocation flow throughout. Fourth, because the demand for permits does not come from a third party (e.g., consumers) but internally from the fringe and the dominant producer, the dominant firm's decision problem is not only the choice of a permits sale/purchase path (or a price path supported by a sales path) but also of an abatement (or demand) path.

To study the dominant firm's problem, let f index the competitive fringe and m

[6] Based on the analysis of Lewis and Schmalensee (1980) for an oligopolistic market, considering two or more large firms and a competitive fringe should not qualitatively alter the main result of this section.

the dominant producer that attempts to manipulate the market. Abatement costs are denoted by $C_f(Q_f(t))$ and $C_m(Q_m(t))$, respectively. Total permits allocations are also as before; although it is useful to make an artificial distinction here between stock and flow allocations.[7] The total flow (or per period) allocation is A_L beginning in $t = 0$ and the total stock allocation is $(A_H - A_L)T_0$. The fringe receives a fraction θA_L of the flow allocation and $\mu(A_H - A_L)T_0$ of the stock allocation, so the dominant firm receives $(1-\theta)A_L$ and $(1-\mu)(A_H - A_L)T_0$, respectively.

Depending on the allocations (and cost structures), the dominant firm can, in principle, manipulate the market during and after the banking period. As explained by Hahn (1985), the after-banking manipulation is only profitable if the allocation θ and costs are such that the dominant producer is either a net seller or buyer of permits after the bank has exhausted. In other words, the dominant firm does not find it profitable to manipulate the after-banking market if it receives a flow allocation exactly equal to the number of permits that it would have demanded in a competitive after-banking market.

Rather than attempt a complete characterization of equilibrium paths for any possible permits allocation, we shall describe the equilibrium path for two illustrative cases. Let us first consider the case in which $\mu = 0$ and θ is such that there is no after-banking manipulation. The latter implies that the after-banking equilibrium price will be as in the competitive solution, i.e., $P^*(T^*)$. When $\mu = 0$, the fringe does not build a bank on its own but buys permits from the dominant producer from the very the first period. The dominant firm, on the other hand, finds it profitable to build and manage a permits

[7] The stock is the cumulative number of permits allocated above the long-term goal of A_L.

bank. Formally, the dominant firm solves

$$\max \quad \int_0^{\infty} [P(t)X(t) - C_m(Q_m(t))]\mathrm{e}^{-rt}dt \tag{12}$$

$$\text{s.t.} \quad P(t) = C_f'(Q_f(t)) \tag{13}$$

$$X(t) = U_f(t) - Q_f(t) - A_f(t) \tag{14}$$

$$\dot{B}_m(t) = A_m(t) - U_m(t) + Q_m(t) - X(t) \qquad [\lambda_m(t)] \tag{15}$$

$$B_m(t) \geq 0 \qquad [\phi_m(t)] \tag{16}$$

$$B_m(0) = 0 \tag{17}$$

where $X(t)$ is the number of permits sold by the dominant firm in period t,[8] $B_m(t)$ is the dominant firm's bank and λ_m and ϕ_m are the multiplier functions associated to the different constraints.

Since firms in the fringe are price takers, it is irrelevant whether the leader solves for $P(t)$ or $Q_f(t)$. Replacing (13) and (14) in the objective function to form the corresponding Hamiltonian $H(Q_f, Q_m)$, the necessary conditions for optimality include satisfaction of (13)–(17) and

$$\frac{\partial H}{\partial Q_f} = [C_f''(Q_f(t))X(t) - C_f'(Q_f(t))]\mathrm{e}^{-rt} + \lambda_m(t) = 0 \tag{18}$$

$$\frac{\partial H}{\partial Q_m} = -C_m'(Q_f(t))\mathrm{e}^{-rt} + \lambda_m(t) = 0 \tag{19}$$

$$\dot{\lambda}_m(t) = -\frac{\partial H}{\partial B_m} = -\ \phi_m(t),\ \phi_m \geq 0,\ \ \phi_m B_m = 0 \tag{20}$$

From (18) and (19) we obtain

$$[C_f'(Q_f(t)) - C_f''(Q_f(t))X(t) - C_m'(Q_m(t))]\mathrm{e}^{-rt} = 0 \tag{21}$$

Eq. (21) shows that if the strategy of the dominant firm is optimal, the discounted value of marginal revenues, $C_f' - C_f''X$,[9] minus marginal costs must be the same (equal to zero)

[8] If the dominant firm act as a monopsonist then $X(t) < 0$.

[9] Note that since $C_f''(Q_f(t)) = \partial P(Q_f(t))/\partial Q_f(t)$, marginal revenues can be expressed as $P(t) - P'(X(t))X(t)$.

in all periods in which the dominant firm sells (i.e., marginal revenues net of marginal costs must rise at the rate of interest) and that at any point in time marginal revenues must be equal to marginal costs.

The characterization of the price path $P(t)$ during the banking period can be obtained from (18). Taking the derivative with respect to time, letting $\dot{\lambda}_m = 0$, and rearranging yields

$$\dot{P}(t) = rP(t) + \dot{C}''_f(Q_f(t))X(t) - rC''_f(Q_f(t))X(t) - C''_f\dot{Q}_f(t) \tag{22}$$

Although we cannot provide a precise characterization of $P(t)$ without a functional form for $C_f(\cdot)$, we can provide a general characterization about how it evolves over time. Because there are no storage costs, we know that arbitrage prevents prices from increasing at anything higher than the discount rate r, i.e., $\dot{P}(t)/P(t) \leq r$. We also know that since marginal cost $C'_m(Q_m(t))$ must increase at the rate of interest (otherwise the dominant firm could rearrange its reduction pattern and save on compliance costs), we must also have that marginal revenues $C'_f(Q_f(t)) - C''_f(Q_f(t))X(t)$ raise at the rate of interest. Provided that $C'_f(Q_f(t) = P(t)$ and $X(t) = U_f(t) - Q_f(t) - A_f(t)$, marginal revenues MR can be re-written as

$$MR(t) = P(t)\left(1 - \frac{1}{\epsilon(t)}\right) \tag{23}$$

where

$$\epsilon(t) = \left(\frac{dC'_f(Q_f(t))}{dQ_f(t)}\frac{X(t)}{P(t)}\right)^{-1} = -\frac{dX(t)}{dP(t)}\frac{P(t)}{X(t)} \tag{24}$$

is the fringe demand elasticity (defined positive). Since ϵ increases with price because $C'_f(0) = 0$ and $C'_f(U_f) = \bar{P} < \infty$, (23) indicates that in equilibrium prices $P(t)$ increase at lower rate than $MR(t)$.[10] Consistent with Salant (1976) and Newbery (1981), when the fringe has no stock, it is optimal for the dominant firm to let prices rise at rate strictly lower than the discount rate, i.e., $\dot{P}(t)/P(t) < r$.[11]

[10] Note that the monopoly and competitive solution would coincide if the fringe's demand for permits (which derives directly from the marginal cost curve) were isoelastic (see Stiglitz, 1976). Such demand structure, however, is not possible here because both the number of permits demanded at $P = 0$ by any fringe member is finite (equal to its unrestricted or counterfactual emissions) and the demand for permits falls to zero above some $\bar{P}$.

[11] Note that if marginal cost curves are linear, $\dot{Q}_f(t)/Q_f(t) = \dot{P}(t)/P(t)$. Replacing this into (22) leads to $\dot{P}(t)/P(t) = r/2$.

Both the competitive and monopoly price paths are depicted in Figure 1. The time at which the dominant firm's bank exhausts is denoted by T^m. Because of the exhaustion condition (8) and $\dot{P}(t)/P(t) < r$, the monopoly path must start above the competitive price and must cross it from above before exhaustion. Figure 1 also shows, as in the exhaustible resource literature, that the dominant firm extends the banking period compared to what would have been observed under perfect competition. The shape of the quantity path $Q(t) = Q_f(t) + Q_m(t)$, which can be derived from the price path, eq. (21) and the exhaustion condition, is similar to that of the price path.

Before we move onto the second case it is important to mention what happens if the dominant firm is also able to exercise market power after the bank has been exhausted (i.e., after T). If the dominant firm is a net seller in the after-banking market, the choke price $P^m \equiv P(T^m)$ will be higher than $P^*(T^*)$ but the rate of price increase will still be lower than the rate of interest. The "choke" price can be readily estimated by solving (21) subject to (14) and $Q_m(T^m) = U(T^m) - A_L - Q_f(T^m)$. If, on the other hand, the firm is a net buyer in the after market, $P^m < P^*(T^*)$ and $\dot{P}(t)/P(t) < r$.

Let us now consider the second case in which the fringe holds all the stock, i.e., $\mu = 1$, and θ is such that the dominant producer is a seller of permits at the end of the banking period.[12] One can think of different candidates for the Stackelberg-rational expectations equilibrium. For example, the dominant firm could propose a price path growing at a lower rate that would induce firms in the fringe to sell all their stock as early as the first period. In the absence of binding contracts, however, this solution is time inconsistent because as soon as the fringe's stock is exhausted the dominant firm will find it profitable to revise its initial price path proposal and rise prices accordingly. Firms in the fringe will anticipate the price jump and, hence, hold on to their permits rather than sell them in the first place.

Since the dominant firm receives no stock, another candidate is one in which the dominant firm builds no bank and the fringe's bank expires at the choke price P^m. Neither can this solution be an equilibrium because the dominant firm sells permits

[12] Same qualitaive results apply if the the dominant firm is a monopsonist at the end of the banking period (the end or "choke" price will be lower than the competitive price).

before the end of the banking period. Since the dominant firm has enough flexibility to support this price path through different sales path (all yielding the same discounted sum of profits of the fringe and the leader), it can chose to accelerate the exhaustion of the fringe's bank by holding on to its permits and selling them only after the fringe bank has been exhausted at $T^f < T^*$ (the time of exhaustion of the fringe's bank is denoted by T^f). But at T^f, the dominant firm would hold a bank and would find its original proposal no longer optimal and would let prices grow (after a possible instantaneous jump) at a rate strictly lower than r until they reach P^m at $T^m > T^* > T^f$. Consequently, the equilibrium path must necessarily have the dominant firm conserving enough permits to keep a stock that it will consume and sell after all firms in the fringe have exhausted theirs, regardless whether it received some of the stock $(A_H - A_L)T_0$ or not.

Without providing the complete market equilibrium solution, the latter equilibrium condition gives us information to qualitatively describe equilibrium price and quantity paths, $P(t)$ and $Q(t)$, respectively. As shown in Figures 2 and 3, there will be three distinctive phases. During phase A, price $P(t)$ rises at the interest rate r and quantities $Q_f(t)$ and $Q_m(t)$ rise accordingly. While the fringe consumes its stock and the dominant firms builds its own, it is not obvious whether the dominant firm participates in the market during this phase (more on this below). At T^f the fringe's bank is exhausted but the dominant firm's bank is positive. In phase B, $P(t)$ rises at a rate strictly lower than r and $Q(t) = Q_f(t) + Q_m(t)$ also grows at a rate strictly lower than under the competitive case since $Q_f(t)$ follows the price path. Furthermore, from the full compliance (or exhaustion) condition, the observed path $Q(t)$ crosses the competitive path $Q^*(t)$ sometime during this phase. At T^m, the leader's bank is exhausted; after which prices remain constant at $P^m > P^*$.

While we have found that the exercise of market power in the after-banking market allows the dominant firm to extend its dominant position to the banking period regardless of the allocation of the permits stock, we have not made precise how the equilibrium path changes with permit allocations (θ and μ) and cost structures and how it deviates from $Q^*(t)$. For that, we need to derive the complete equilibrium solution. In particular, we need to determine T^f and T^m, or alternatively $P(0)$.

The solution must not only be time consistent and exhibit the market power of the dominant firm after the fringe's bank has expired, but one can argue that it should also make some use of the ability of the dominant firm to alter the stock of the fringe during the competitive phase, i.e., phase A, by either selling or buying permits. But in the absence of binding contracts, the latter possibility will be time inconsistent in the sense that the dominant firm would continuously like to revise its original price path after each transaction.[13] To overcome these objections and still allow the dominant firm to be more active during the competitive phase, Newbery (1981) argues that the Nash-Cournot equilibrium appears to be the best approximation to the rational expectations Stackelberg equilibrium.[14] In our context, however, such approximation looks less attractive to the leader, since in a permits market where there is no third party demand, the Nash-Cournot equilibrium coincides with the Nash bargaining solution (Spulber, 1989) in which $P = C'_f(Q_f) = C'_m(Q_m)$.

Although we cannot provide at this point what we believe to be the most reasonable equilibrium solution,[15] a better candidate than the above is for the dominant firm to refrain itself from any permits transaction during the competitive phase and only start selling permits at T^f. This tentative solution can be found by first imposing a continuous price path that ends at P^m; the monopoly price that prevails when there is no bank left and which can be easily obtained from (21). From 0 to T^f (the time at which the fringe's bank is exhausted) $\dot{P}(t)/P(t) = r$, and from T^f to T^m (the time at which the dominant firm's bank is exhausted) $\dot{P}(t)/P(t) < r$ according to (22). At T^m and after, $P(t) = P^m > P^*(T^m)$.

The rest of the solution (i.e., T^m and T^f) is found by simultaneously solving the two "exhaustion" conditions: the fringe's bank expires at T^f and the dominant firm's bank expires at $T^m > T^f$. Since the dominant firm does not trade between 0 and T^f, these

[13] Since the dominant firm's optimal sale or purchase is a function of the fringe' stock, the ex-ante (i.e., before the transaction) optimal solution differs from the ex-post optimal solution. The rational expectations Stackelberg equilibrium derived by Gilbert (1978) in his example does not have this dynamically inconsistency problem because he uses a constant demand elasticity (besides equal discount rates and zero extraction costs), which is not our case.

[14] The Nash-Cournot equilibrium is also used by Salant (1976).

[15] See Liski and Montero (2003) for a discussion of all the different issues that must be addressed in finding such a solution.

two conditions can be written as

$$\int_0^{T^f} Q_f(t)dt = (U_f - \theta A_L)T^f - \mu(A_H - A_L)T_0 \tag{25}$$

$$\int_0^{T^m} (Q_f(t) + Q_m(t))dt = (U - A_L)T^m - (A_H - A_L)T_0 \tag{26}$$

where $U_f = U - U_m$.

The fringe's abatement path $Q_f(t)$ follows the price path according to $C_f'(Q_f(t)) = P(t)$. The dominant firm's abatement path $Q_m(t)$, on the other hand, must minimize the present value of the dominant firm's compliance costs during the banking period, hence, $C_m'(Q_m(t))$ must grow at r until it reaches its long-term level at T^m (this value can also be obtained from (21)). Replacing these abatement paths and the price path on the above two conditions, T^f and T^m are finally found.

4 Final Remarks

We have investigated the effect of market power on the equilibrium path of an emission permits market in which firms can bank current permits for use in later periods. In particular, we study the market equilibrium for a large (potentially dominant) firm and a competitive fringe with rational expectations. Although we do not provide a full description of the equilibrium solution for all combination of permits allocations and cost structures, we provide a characterization of the equilibrium solution for a few illustrative cases. For example, we find that if the large firm enjoys a dominant position in the after-banking market, it can always extend this dominant position to the market during the banking period regardless of the allocation of the stock (bank) of permits.

Based on the preliminary results of our parallel work (Liski and Montero, 2003), it should be mentioned that the full characterization of the market equilibrium for any permits allocation is not a trivial exercise (e.g., when the large firm receives only a large fraction of the stock of permits but does not enjoy a dominant position in the after-banking market). It requires to address problems of time inconsistency and reputation building. Time inconsistency arises because the dominant firm has incentives to alter its original path proposal as time passes. Since the fringe correctly anticipates this possibility, the dominant firm may be unable to credibly sustain anything different than the competitive path (this is similar to the Coase conjecture problem). Under some circumstances, however, one may argue that it could be possible for the dominant firm to credibly sustain a more profitable path as a subgame perfect equilibrium. To find out whether and when the latter can be the case, much more work remains to be done.

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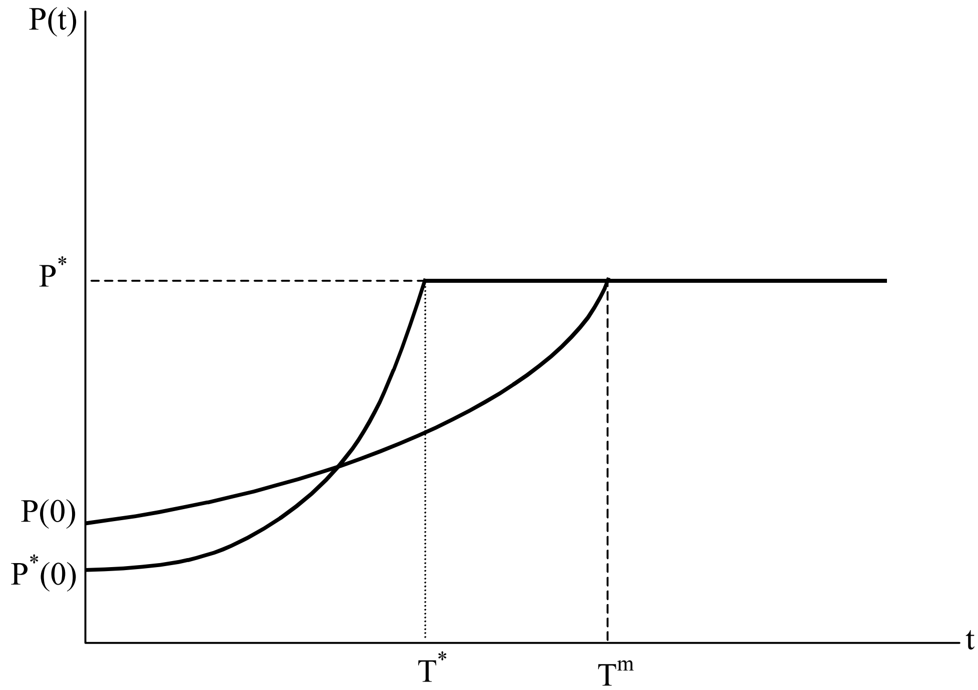

Figure 1: Price path for a dominant firm with all the permits stock

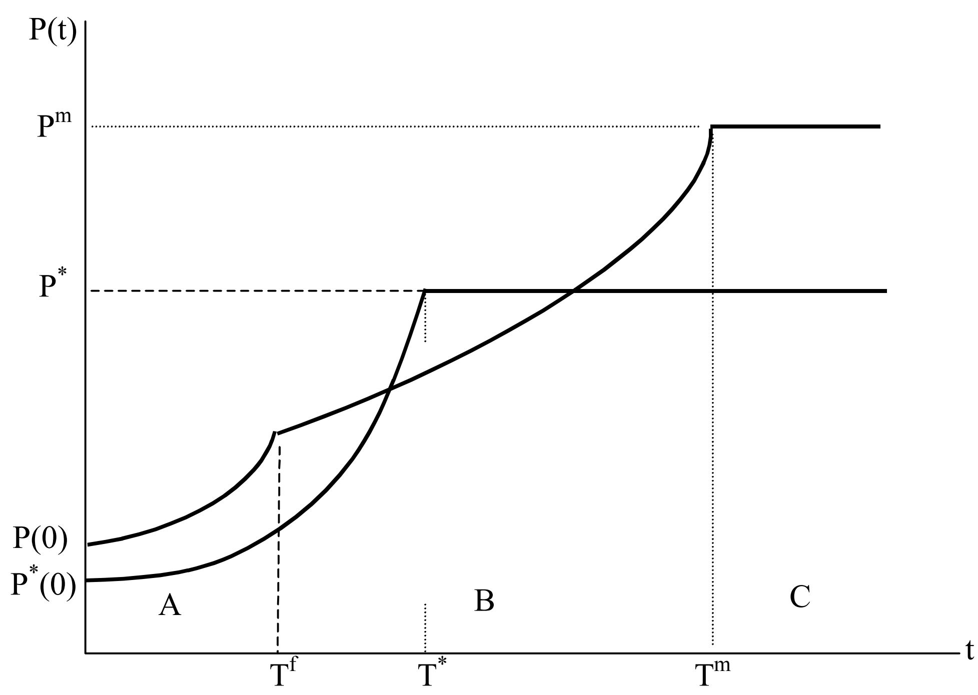

Figure 2: Effect of market power on the price path

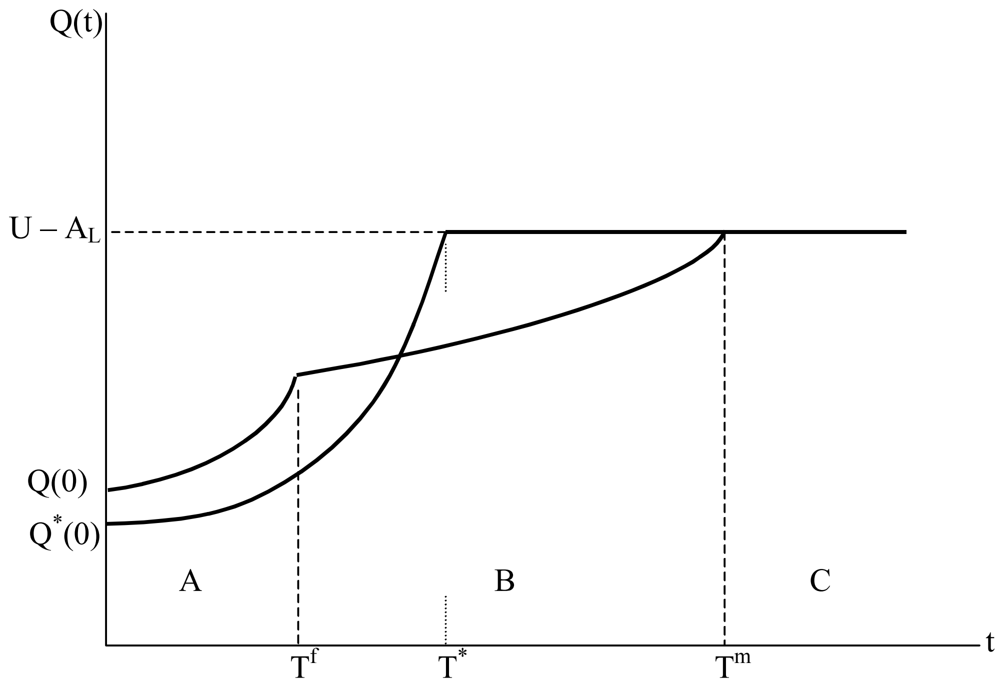

Figure 3: Effect of market power on the abatement (quantity) path