MARKET POWER IN PRICE-REGULATED POWER INDUSTRIES*

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Abstract

This paper analyzes market power in price-regulated power industries. We derive market equilibrium under different assumptions (perfect competition, monopoly, Cournot, etc.), with and without free entry. We show that when peak-load pricing is used, producers can exercise market power by increasing the share of peaking technology in the generation portfolio, compared to the welfare-maximizing configuration. In this framework natural measure of market power is the length of time that peaking technology plants operate beyond their operational time in the welfare maximizing solution. We show that when there is free entry with an exogenous fixed entry cost that is later sunk, more intense competition results in higher welfare but fewer firms.

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1. Introduction

Recent years have seen a boom in papers that study market power issues in the electricity sector, motivated by the wave of deregulation that has spread throughout the world with varying degrees of success, and by recent experiences of the exercise of market power by generation companies—California being the most notable case in point. This literature has focused on industries where the price is determined by the interaction between producers and consumers, thereby creating a vacuum for policy makers in price-regulated power industries. Accordingly, this paper analyzes the exercise of market power in a price-regulated power industry, subject to centralized dispatching based on merit order—a regulatory scheme that is widely used in Latin America.

We are unaware of any other paper that analyzes market-power issues in price-regulated industries. This situation may be explained by the widespread but erroneous assumption that market power cannot be exercised if prices reflect marginal costs. We adapt the traditional imperfect competition model to analyze industries operating under centralized merit-order dispatch and peak-load pricing. We assume that only two generating technologies are available: peaking and base-load, where the former has a lower per unit capacity cost but a higher unit operating cost. In this setting producers define their strategies over the composition of their generating portfolios, which is the only variable they are able to control.

We show that even where prices are set equal to marginal costs, producers can still exercise market power by altering the composition of their generating portfolios; generators can earn rents by increasing the share of peaking technology in the generating portfolio beyond its welfare-maximizing level. This strategy raises the average price paid by consumers, since the peaking technology sets the energy price for a longer period, while the capacity charge remains unchanged. In this context, market power should not be measured by the traditional price–cost margin, but by the length of time for which peaking technology plants operate over and above the welfare maximizing solution. We also show that when the number of firms is fixed, then the more intense is competition the higher is social welfare. Lastly we consider free entry with an exogenous fixed entry cost that is later sunk, and show that more intense competition results in higher welfare but fewer firms.

Three different approaches have been used to simulate the strategic behavior of generating firms in deregulated markets: supply function equilibrium, based on the work of Klemperer and Meyer (1989), Green and Newberry (1992) and Halseth, 1998; auction theory (Von der Fehr and Harbord, 1993); and Cournot competition (Andersson and Bergman, 1995; Borenstein and Bushnell, 1999; Bushnell, 1998; and Arellano, 2004). There appears to be a consensus in this literature that market power can be exercised more freely when the capacity of rivals is exhausted, which usually occurs when demand is high, since the residual demand faced by the dominant firms becomes less elastic. As the price paid by consumers is higher than marginal cost in the relevant periods, the market equilibrium is allocatively inefficient. Moreover, if generators keep plants with low operating costs out of the market to drive the price up, then the equilibrium is also productively inefficient. In contrast to this literature, in our model the exercise of market power tends to distort investment decisions.

2. The basic model

We assume a two-technology, linear-cost generating industry, where 1 denotes the base-load technology and 2 the peaking technology. In addition c_i denotes the operating cost per unit and f_i the capacity cost per unit, for technology i, i=1, 2. Hence $f_1 > f_2$ and $c_1 < c_2$. Demand, which is assumed to be inelastic, is summarized in a load curve $q(\,)$ which is assumed to be continuously differentiable, where $q(t)$ designates consumption at the t-th highest consumption hour. Lastly, we assume that (i) plants are always available to produce at full capacity and can adjust their production level instantaneously and costlessly;[1] (ii) plant startup costs can be neglected; and (iii) no failures occur. On this set of assumptions, the problem of minimizing the total cost of the electric power system is formalized as follows:

[1] This excludes hydroelectric plants which are limited by water accumulated in the reservoir.

$$\underset{k_1}{Min}\ C(k_1) = \underset{k_1}{Min}\left\{f_1 k_1 + f_2(q^M - k_1) + c_2\int_0^{t(k_1)}(q(t) - k_1)dt + c_1 k_1 t(k_1) + c_1\int_{t(k_1)}^T q(t)dt\right\} \quad (1)$$

where q^M designates maximum systemic demand, k_i the installed capacity of type i technology, and T the number of hours in a year. The formalization of the problem assumes optimal use of installed capacity (see figure 1). Indeed, installed capacity equals maximum demand, and peaking plants are dispatched only when base-load plants are operating at full capacity. In fact, between hours $t(k_1)$ and T, demand is met by base-load plants only, since installed capacity renders this feasible. Between hours 0 and $t(k_1)$, peaking plants generate the demand unmet by base-load plants. Thus, in what follows, $t(k_1)$ will stand for the number of hours in which peaking plants operate.

Differentiating $C(k_1)$ gives:

$$C'(k_1) = \left(\frac{\Delta f}{\Delta c} - t(k_1)\right)\Delta c \quad (2)$$

Since $C(k)$ is a convex function, the optimal solution is characterized by the condition:

$$t^* = Min\left(\frac{\Delta f}{\Delta c}, T\right) \quad (3)$$

and the generating portfolio that minimizes the overall system cost is $k_1^* = q(t^*)$, and $k_2^* = q^M - k_1^*$. When $t^* = T$, only technology-2 plants are set up.

Peak-load pricing consists of an energy charge equal to the per unit operating cost of the plant with highest operating cost being dispatched at any instant (i.e. the marginal plant) and a capacity charge equal to the marginal cost of increasing capacity, where the latter corresponds to the per unit capacity cost of the peaking technology. The capacity charge applies only to customers that consume at peak demand. Then, assuming than an independent operator dispatches generating plants in strict merit order, peak-load pricing will lead a decentralized competitive system to the optimal solution. When the price of energy is c_1, only base-load plants are willing to produce, whereas at price c_2, both types of plants are willing to produce. Moreover, under perfect competition the configuration of the generation portfolio is optimal. Base-load capacity will be installed up to the point where rents are dissipated, which happens when peaking plants operate for t^* hours.

Since peaking plants never obtain rents, for any level of base-load installed capacity (k_1) the industry's profits are given by:

$$\pi(k_1) = k_1 t(k_1)\Delta c - k_1 \Delta f \tag{4}$$

with

$$\pi'(k_1) = t(k_1)\Delta c + k_1 t'(k_1)\Delta c - \Delta f \tag{5}$$

Although perfect competition, combined with mandatory merit-order dispatching and peak-load pricing, results in zero rents for the power industry ($\pi(k_1^*) = 0$), the industry could generate rents by altering the composition of its generating portfolio. To see this, note that $\pi'(k_1^*) = k_1^* t'(k_1^*)\Delta c < 0$. Hence, although prices are set equal to marginal costs there is a range in which reducing the share of base-load plants in the generating portfolio $(k_1 < k_1^*)$ increases profits. Also note that $\pi'(0) = T\Delta c - \Delta f > 0$. As the function t is assumed to be continuously differentiable, it follows that function π' is continuous. Consequently there is at least one $k_1 \in (0, k_1^*)$ satisfying the condition $\pi'(k_1) = 0$. To simplify analysis we further assume that the profit function π is concave; hence there is only one solution to $\pi'(k_1) = 0$.

Turning to consumers, their payments are given by:

$$P(k_1) = c_2 \int_0^{t(k_1)} q(t)dt + c_1 \int_{t(k_1)}^{T} q(t)dt + f_2 q^M \tag{6}$$

Hence

$$P'(k_1) = k_1 t'(k_1)\Delta c < 0 \qquad (7)$$

Thus a higher share of peaking technology in the generating portfolio always results in larger consumer payments. Moreover, consumers' losses outweigh the gains made by generating companies, thereby reducing social welfare. In fact, $C'(k_1)=(P'(k_1)-\pi'(k_1))<0$ when $k_1 < k_1^*$.

3. Imperfect competition with no entry

In this section we firstly analyze market equilibrium when the number of firms is given. As before, we assume mandatory dispatching by an independent operator who minimizes total operating cost and applies peak-load pricing. This ensures that generators are willing to satisfy demand since peaking plants always break even.[2] In this context, the only decision left to generation companies concerns the composition of their generating portfolios.

3.1 Monopoly

The solution that maximizes the monopolist's profits satisfies the condition $\pi'(k_1) = 0$. Rearranging equation (5) gives:

$$t^m = \frac{e_q^m}{1+e_q^m}\frac{\Delta f}{\Delta c} = \frac{e_q^m}{1+e_q^m} t^* \qquad (8)$$

where t^m denotes the number of hours that peaking technology plants are dispatched and e_q^m the elasticity of function $q(t)$ assessed at t^m. The concavity of the profit function ensures that $t^m \in (t^*, T)$, i.e. that peaking technology plants set the price of energy for a longer period of time under monopoly than under perfect competition. Moreover $k_1^m < k_1^*$ and

[2] Thus only the number of firms with access to base-load technology needs to be fixed.

$k_2^m > k_2^*$, where $k_1^m = q(t^m)$ and $k_2^m = q^M - k_1^m$ (see figure 2). Accordingly, the monopolist's generating portfolio has a smaller share of base-load technology than the welfare maximizing pattern.

3.2 Cournot Oligopoly

Let us now assume that there are *n* generating companies, all of which have access to both technologies. We assume Cournot competition, i.e. each generating company chooses its base-load installed capacity, taking its rivals' base-load installed capacities as given. Hence the profit maximization problem of firm *j* is:

$$\underset{k_1^j}{Max}\left\{\Delta c\, k_1^j\, t(k_1) - \Delta f\, k_1^j\right\} \tag{9}$$

where k_1^j denotes the choice of base-load installed capacity by firm *j*; and, as before, k_1 denotes the system's base-load total installed capacity. Each generating company's first-order condition is:

$$t(k_1) + t'(k_1)k_1^j - t^* = 0 \tag{10}$$

By symmetry, $k_1^j = k_1/n$, so (10) can be rewritten:

$$t(k_1)\left[1 + \frac{1}{ne_q(t(k_1))}\right] = t^* \tag{11}$$

Therefore, peaking plants operate between $t=0$ and $t^c(n)$, where

$$t^c(n) = \frac{ne_q^c(t^c(n))}{1 + ne_q^c(t^c(n))}t^* \tag{12}$$

and $e_q^c(n)$ is the elasticity of function $q(t)$ assessed at $t^c(n)$. In the appendix we show that the concavity of the profit function ensures that $t^c(n) \in (t^*, t^m)$ and that $t^c(n)$ is decreasing in n. Consequently, $t^* < t^c(n) < t^c(n-1) < t^m$ (see figure 2). Hence $k_1^* > k_1^c(n) > k_1^c(n-1) > k_1^m$, where $k_1^c(n) = q(t^c(n))$. Thus, the larger the number of firms, the larger the share of base-load plants in the generation portfolio and the smaller the generating companies' market power.

3.3 General case

In this section we analyze equilibria for different levels of market power. The standard measure of market power, the Lerner index, is given by:

$$\frac{p - MC}{p} = -\frac{\theta}{e_p}, \tag{13}$$

where p is the price, MC the marginal cost and e_p the price elasticity of demand. θ is a conduct parameter such that $0 \leq \theta \leq 1$, with $\theta = 1$ corresponding to monopoly, $\theta = 0$ to perfect competition, and $\theta = 1/n$ to Cournot with n symmetric firms. In a price-regulated power industry, the natural measure of the exercise of market power would be the length of time that peaking technology plants operate beyond their operational time in the welfare maximizing solution. Hence, by analogy the market power index would be:

$$\frac{t - t^*}{t} = -\frac{\hat{\theta}}{e_q(t)} \tag{14}$$

where t is the length of time for which the peaking technology plants operate, and $\hat{\theta}$ is the relevant conduct parameter. Since having a higher share of base-load plants in the generating portfolio results in losses, we can assume that $t \geq t^*$ without loss of generality. Hence $0 \leq \hat{\theta} \leq 1$, with $\hat{\theta} = 0$ for perfect competition, $\hat{\theta} = 1$ for perfect collusion (or monopoly), and $\hat{\theta}$ = *1/n* for the Cournot oligopoly with *n* symmetric firms. Rearranging equation (14) leads to,

$$t(\hat{\theta}) = \frac{e_q(t)}{e_q(t)+\hat{\theta}} t^* \qquad (15)$$

The concavity of the profit function ensures that $t(\hat{\theta})$ is a decreasing function of $\hat{\theta}$, so the more market power is exercised by generators, the larger is the share of peaking technology plants in the generating portfolio and the longer is their operating time.

In order to analyze the effect of industry structure on the equilibrium, it is convenient to rewrite the conduct parameter used in equation (15) in terms of *n* and *g* where $\hat{\theta} = 1/(gn)$. Hence *g* is a measure of the intensity of competition, which ranges from *1/n* (perfect collusion) to infinity (perfect competition). Equation (15) may therefore be rewritten as:

$$t(n,g) = \frac{e_q(t)gn}{1+e_q(t)gn} t^* \qquad (16)$$

In the appendix we show that, assuming the function π to be concave, and for a given intensity of competition g, the larger the number of firms n in the industry the less distorted is the composition of the generating portfolio, except for the polar cases of perfect collusion and perfect competition.

Assuming that every entrant incurs an entry cost σ, the system's total cost function is given by

$$C(t,n) = f_1 q(t) + (q^M - q(t)) f_2 + c_2 \int_0^t (q(s) - q(t))ds + c_1 t q(t) + c_1 \int_t^T q(s)ds + n\sigma \qquad (17)$$

Increasing the number of firms has two contrary effects on total cost and therefore may be not necessary socially desirable. To see this, note that

$$\frac{dC(t,n)}{dn} = -q'(t)\Delta c(t-t^*)\frac{dt}{dn} + \sigma \qquad (18)$$

It is not clear whether the cost reduction resulting from less market power compensates for the entry cost that must be incurred by each entrant.

4. Equilibrium with free entry

Next we analyze free entry, following Sutton (1996) in assuming a fixed cost σ that is sunk once entry occurs. Among other things, this entry cost includes the costs of setting up the firm, understanding regulation and forecasting rivals' behavior. Market equilibrium may then be formulated as a two-stage game. In the first stage, the entry decision is taken with perfect foresight regarding the intensity of competition *g* in the next stage; while at the second stage competition occurs between the firms that have entered the market. The result of the latter stage is the equilibrium described in section 3.

The relation between the distortion of the generating portfolio and the number of firms (equation 16) is plotted as line TT in figure 3. Moreover, for any industry structure, an increase in the intensity of competition reduces market power and thus moves the curve TT downwards. A homothetic expansion of demand, i.e. one that increases each hour's demand in the same proportion, has no impact on the TT curve.

Assuming symmetric firms and recalling equation (4), the zero-profit condition that results from free entry is given by:

$$n^{FE} = \frac{\pi(q(t))}{\sigma} \qquad (19)$$

As in this model the exercise of market power is measured by the length of time that peaking technology plants operate beyond their operational time in the welfare maximizing solution, π is an increasing function of *t-t** in the relevant range. Therefore, the zero-profit condition (19) is plotted by the upward sloping curve *FEC* in figure 3.

Either a reduction in the entry cost σ or a homothetic expansion of demand shifts the *FEC* curve downwards.

Equilibrium with free entry is represented by the intersection of curves TT and FEC in figure 3, and formally obtained from the joint solution of equations 16 and 17. An increase in the intensity of competition thus reduces both market power and the number of firms. The more intense the competition, the larger each firm's sales must be for them to break even, and consequently the smaller the number of firms that can coexist in the industry (recall that demand is inelastic). Lastly a rise in the entry cost results in a more concentrated industry and in greater exercise of market power; a homothetic expansion of demand has opposite effects.

5. Final Comments

This paper adapts the traditional analysis of imperfect competition to a price-regulated power industry with centralized dispatch based on merit order. Our results show that even when prices are set equal to marginal costs, generators can obtain rents by increasing the share of peaking technology in the generation portfolio above the welfare-maximizing level. This strategy raises the average price paid by consumers, since the peaking technology sets the energy price for a longer period, while the capacity charge remains unchanged. When the number of plants is fixed, the more intense is competition the less market power is exercised and the higher is social welfare. Lastly, we show that with free entry, more intensive competition results in higher welfare and fewer firms.

Our treatment of the intensity of competition is quite abstract. However, since in the context of this paper, producers make their investment decision in an initial stage, with later production and pricing decisions emulating price competition, our belief is that Cournot competition is the most likely outcome. Therefore the policies that could force generators to behave more competitively need to be understood.

A competitive contract market, in which producers and consumers interact on a winner-takes-all basis may provide such incentive. If so, the game would have an intermediate stage in which producers sell a fraction of their production to consumers through financial contracts. Such contracts would have to be backed by installed capacity. Once contracts were signed, generators would have to make their investment decisions to supply the remaining spot market. Assuming that centralized dispatch also encompasses contracted energy, it can be shown that consumers and generating companies are willing to buy and sell contracts, respectively. The former, because the average price they pay is lower than the average charged in the spot market; while producers are willing to sacrifice profits in the contract market because they expect their plants to be dispatched later for a longer period of time, and, given that production will exceed their contracted sales, the excess will be sold in the spot market at a profit

It is interesting to note that, in this model, contracts would play a similar role as in the context of traditional imperfect competition models, for which it has been shown that the more contracted a producer is, the less incentive there is to exercise market power because a smaller portion of its revenues comes from the spot market. The natural sequel to this research would be to extend the formal model to include an intermediate stage in which producers are allowed to contract.

Since we assume that plants can permanently generate at full capacity, the model is only valid for thermal power industries. A further line of research should consider an industry with a mixed hydro-thermal portfolio and thus extend the model to include the possibility of shifting water from one period to another.

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FIGURE 1

Optimal composition of the generating portfolio

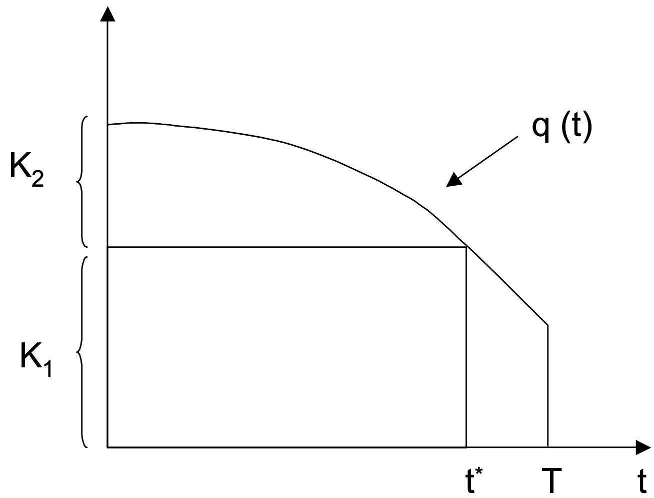


FIGURE 2

Composition of the generating portfolio under different competition regimes

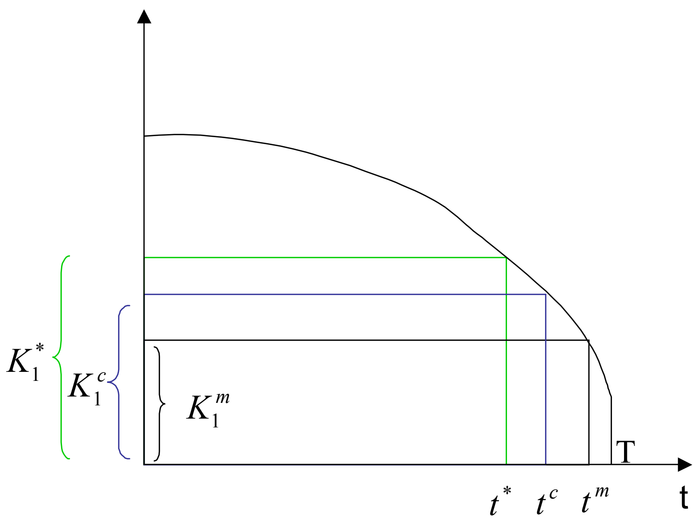
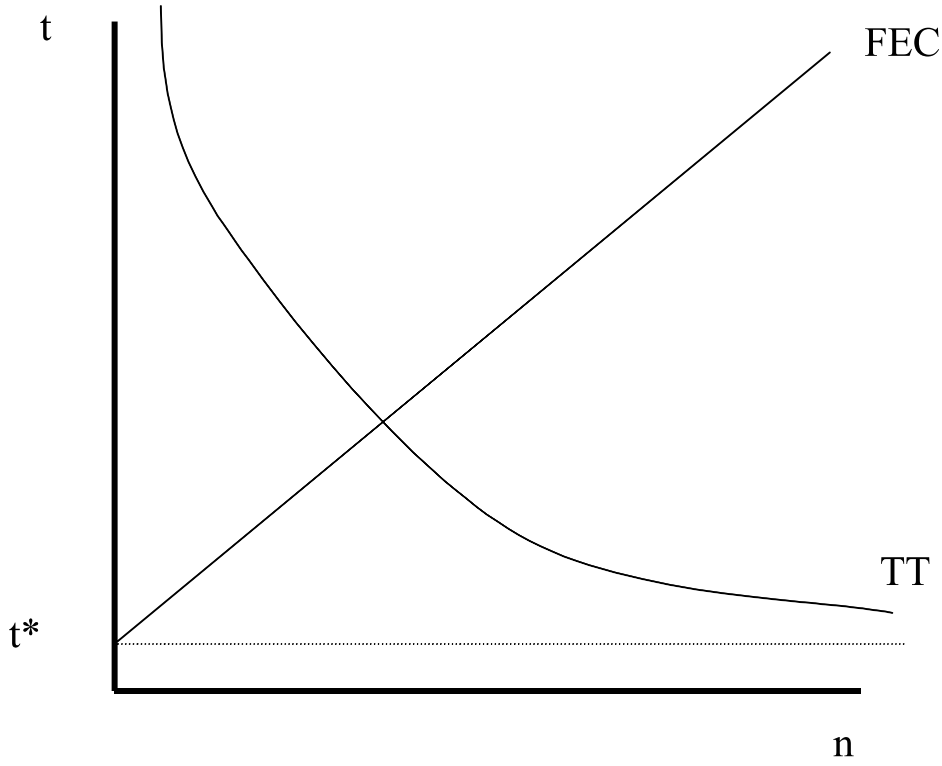


FIGURE 3
TT and FEC curves



Appendix

For simplicity we rewrite the profit maximization problem (4) as a function of the time t that peaking plants are operational, i.e.

$$\pi(t) = tq(t)\Delta c - q(t)\Delta f \qquad \text{(A1)}$$

Thus

$$\frac{d\pi(t)}{dt} = q(t)\Delta c + q'(t)(t - t^*)\Delta c \qquad \text{(A2)}$$

and

$$\frac{d^2\pi(t)}{dt^2} = 2q'(t)\Delta c + q''(t)(t - t^*)\Delta c \qquad \text{(A3)}$$

Noting that in the optimal solution $t - t^* = -q(t)/q'(t)$, the concavity condition may be written as:

$$q''(t) \le -\frac{2q'(t)}{t - t^*} = \frac{2(q'(t))^2}{q(t)} \qquad t^* \le t \le T \qquad \text{(A4)}$$

We next show that condition (A4) guarantees that the time for which peaking plants operate diminishes with either the number of firms or the intensity of competition. Consider the solution *t* to equation

$$t = \frac{e_q(t)}{\hat{\theta} + e_q(t)} t^*, \qquad x \ge 1 \qquad \text{(A5)}$$

Defining $x=ng$, the above equation can be rewritten as:

$$t(x) + x(t(x) - t^*)e_q(t(x)) = 0 \qquad \text{(A6)}$$

To see how *t* depends on *x* we differentiate the equation (A6):

$$(1 + x(t - t^*)e_q'(t(x)) + xe_q(t(x)))t'(x) + e_q(t(x))(t - t^*) = 0 \qquad \text{(A7)}$$

Hence *t'(x)* is negative if and only if

$$1 + x(t - t^*)e_q'(t(x)) + xe_q(t(x)) < 0\,. \qquad \text{(A8)}$$

Thus if the above condition is satisfied, the time for which peaking plants operate diminishes with either the number of firms or the intensity of competition. Next we show that condition (A4) implies (A8). To simplify notation *t(x)* will be denoted *t*. In fact,

$$e_q'(t) = \frac{t}{q(t)} q''(t) + \frac{q'(t)}{q(t)} - \frac{q'(t)^2 t}{q(t)^2} \tag{A9}$$

Hence condition (A8) becomes:

$$-\frac{q''(t)}{q'(t)} + (1+x)\frac{q'(t)}{q(t)} < 0 \tag{A10}$$

Or

$$q''(t) \leq \frac{(1+ng)q'(t)^2}{q(t)} \tag{A11}$$

Since $g \in [1/n, \infty]$, condition (A4) guarantees that (A8) always holds.