Impact of Regional Market Power on Natural Gas Transport Network Size

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Abstract

This paper focuses on the size of natural gas transport capacity as a means to fight regional market power. Starting from a model in which the network operator has three instruments to control a local monopoly, namely, transfers between consumers and the firm, price/output, and capacity, we compare the policy prescriptions of this control scheme and two others in which the set of control instruments is restrained (without transfers and without price control). The analysis allows us to identify conditions under which the objective of mitigating regional market power results in either over- or down-sizing of the transport network.

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1 Introduction

Natural gas markets are being liberalized all around the world and imports through existing or newly built pipelines and Liquefied Natural Gas (LNG) liners are playing a major role in the reshaping of the industry. An issue of great interest is the extent to which regional imperfectly competitive markets are going to hinder this liberalization process.[1] The question then is what types of policies, including imports, are to be implemented by network operators concerned by the exercise of market power by incumbent local monopolies.[2] This paper considers a sample of such policies and analyzes their impact on the natural gas transport network.

The focus of the analysis is the degree to which alternative policies are substitutes or complements as remedies to alleviate the allocative inefficiency stemming from the exercise of local market power by gas suppliers. More specifically, we assume that the instruments available to the network operator to accomplish this goal are price control, import capacity dimensioning, and transfers between consumers and an incumbent local monopoly. We control for any productive inefficiency by assuming that imported and local gas units are produced at the same marginal cost. Then, we derive the optimal policy starting with the case where the network operator has a set of three control

[1]This issue is particularly relevant for Europe.

[2]Indeed, imports play an increasing role in some important markets as the following citation from the World Energy Investment Outlook (2003), published by the International Energy Agency (IEA) suggests: "The United States and Canada, which together imported 250 billion cubic feet of natural gas from other countries in 2001, will see gas imports skyrocket in the coming decades as production from their mature basins continues to decline." Note that this role can be seen as going beyond that of merely meeting increasing demand.

instruments and progressively restraining this set up to the situation where the network operator only controls the size of the natural gas import capacity.

As the set of instruments available to the network operator becomes smaller, one might expect that the remaining tools are more intensively relied upon to fight market power. A consequence would then be that a lack of transfers or price control would have to be compensated by a larger availability of capacity possibly leading to an "excess" of it. This effect has been explored by Cremer and Laffont (2002).[3] Our model generalizes the Cremer and Laffont framework by enlarging the set of available control instruments and allows us to characterize situations of both over- and under-dimensioning of the import capacity.

The plan of the paper is as follows. The next section presents the basic ingredients of the model. In section 3 we derive the optimal policy of a control scheme in which the network operator controls a local monopoly gas supplier by means of transfers between consumers and the firm, price/output, and import capacity. Then, we withdraw one control instrument at a time. Section 4 rules out transfers and section 5 assumes that the network operator can only control capacity. Section 6 reexamines the policy prescriptions of the three control schemes and attempts to draw conclusions regarding the impact of these policies that seek to fight market power on the import capacity.

[3]In the same spirit and for electricity, Borenstein et al. (2000) show how additional transmission capacity, even if it is not actually used, is an effective policy for promoting competition.

2 Basic market configuration

Consider a regional natural gas market, market M, dominated by an incumbent single supplier, firm m, producing output q_m at variable cost $C^m(q_m) = cq_m$, where c is marginal cost, and fixed cost F_m.[4] Gas is also supplied at this same marginal cost c in a perfectly competitive market, market C_p, which is geographically distinct from market M but could be linked to it by means of a pipeline of capacity K built at variable cost $C(K)$, where $C(.)$ is an increasing convex function such that $C'(0) = 0$ and $C''(0) > 0$.[5] In this simple two-market configuration (see Figure 1), gas flowing from market C_p into market M would exert competitive pressure on the regional monopoly and hence mitigate the exercise of market power by firm m in its local market.

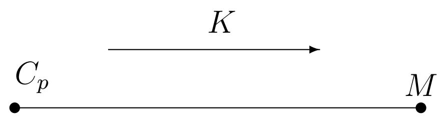

Figure 1: Basic market configuration

The analysis conducted in this paper rests on the presumption that the transport line linking these two markets would be built by the network owner/operator for the purpose of allowing imports of gas from market C_p into market M. Letting $Q_M(.)$ represent the downward-sloping demand function in market M, if a quantity of gas corresponding to full capacity of the pipeline, K, is shipped from the competitive market into market M,

[4]Even though when solving for the optimal policies considered in this paper we allow for the shutting down of this monopoly, we assume that this fixed cost is sunk.

[5]The assumption that the monopoly supplies gas at the same marginal cost as the competitive market allows us to control for any productive inefficiency when analyzing the policy effects of the allocative inefficiency due to regional market power.

the supplier in this market would be a monopoly on the residual demand $Q_M(p_M) - K$ where p_M is price.

We now proceed to characterize the prescriptions of various policies that are used to control market power in the regional market M.[6] It is worthwhile noting that, given the structure of the model, any pricing policy that is implemented in the regional monopoly market wouldn't affect welfare in the competitive market since price in the latter is at the first-best (marginal-cost) level. Hence, without loss of generality, we can ignore welfare of consumers and firms in this competitive market.[7]

We start from a situation where the network operator has the ability to control the gas supplier's market power by means of three instruments, namely, (possibly two-way) transfers between consumers and the firm, price (or equivalently output), and transport capacity of the network. We then restrict the set of control instruments available to the network operator. We first consider the case where the operator may not use transfers when he sets the price and capacity levels. Then, we examine the situation where besides the fact that transfers are not allowed, the network operator looses the ability to control price.

[6]In this paper we assume that control of the monopoly is exercised under complete information. In a paper in progress (Gasmi et al., 2004), we introduce asymmetric information on the technology of gas production.

[7]Another factor that is also neglected in the analysis without affecting its main qualitative results is the marginal cost of transport. Alternatively, if marginal cost of transport is constant it can be included in the constant c, i.e., we may write $c = c_p + c_t$ where c_p is now the marginal cost of production in the competitive market and c_t is the marginal cost of transport.

3 Controlling the local monopoly with price, capacity, and transfers

In this section we assume that the network operator, whose objectives coincide with those of the government, may use public funds raised through taxes to operate transfers between consumers and the firm. The economic distortions (the deadweight loss) generated by taxation are captured through a nonzero social cost of public funds λ. That is, if the network operator makes a monetary transfer T to the firm, this transfer costs consumers $(1+\lambda)T$.

Let $S(.)$ represent the utility function of consumers in market M. Total supply of gas $Q_M(p_M)$ in this market, composed of K units imported from the competitive market and q_m units produced locally by the firm, brings consumers an aggregate net welfare, V,

$$\begin{aligned} V = \;& S(Q_M(p_M)) - p_M Q_M(p_M) \\ & + (1+\lambda)\left[(p_M - c)K - C(K)\right] - (1+\lambda)T \end{aligned} \tag{1}$$

This consumers' net welfare is composed of three terms: the net surplus of consumers, the social valuation of profits generated by the K units of gas provided competitively, and the social cost of the transfer made to the firm.

As to the regional monopoly welfare, denoted U, it is given by the sum of its profits and the transfer it receives from the network operator:

$$U = (p_M - c)\left[Q_M(p_M) - K\right] - F_m + T \tag{2}$$

For the firm to be willing to supply gas at all, the network operator ought to guarantee it a given level of utility. This participation constraint is normalized to

$$U \geq 0 \tag{3}$$

The utilitarian social welfare function, W, is defined as the unweighted sum of aggregate consumers' net welfare V and firm's utility U:

$$W = V + U \tag{4}$$

Substituting for V from (1) and for T from (2) yields social welfare

$$\begin{aligned} W = \quad & S(Q_M(p_M)) + \lambda p_M Q_M(p_M) \\ & -(1+\lambda)\left[cQ_M(p_M) + F_m + C(K)\right] - \lambda U \end{aligned} \tag{5}$$

as the social valuation of the total production, minus its social cost, minus the social opportunity cost of the firm's utility. From this expression of social welfare we see that reducing the monopoly's utility is a socially desirable objective, for this utility includes a transfer of funds collected through distortive taxation (see (2)). Relatedly, we see from (5) that the social valuation of total production explicitly includes the fiscal value of the revenues that it generates.[8]

The regulatory program consists in maximizing social welfare W given by (5) with respect to p_M and K, under the participation constraint (3).[9] From the expression of social welfare, we immediately see that the participation constraint is binding. Hence, the availability of transfers allows the network

[8]Indeed, these revenues allow the government to lessen the need to rely on distortive taxation.

[9]To be somewhat more realistic, one can assume a timing of decisions such that the network operator sets up first the capacity level and then the price level. Solving this problem by backward induction and using the envelope theorem yields the solution that is characterized in Proposition 1.

operator to extract the firm's profit through taxation. Substituting for $U = 0$ in (5) and using the fact that $\partial S(Q_M)/\partial Q_M = p_M$, we obtain the following first-order conditions:[10]

$$(1+\lambda)Q'_M(p_M - c) + \lambda Q_M = 0 \tag{6}$$

$$-(1+\lambda)C'(K) = 0 \tag{7}$$

Letting $\eta(Q_M) \equiv -Q'_M p_M/Q_M$, represent the price-elasticity of demand in market M, the following proposition holds:

Proposition 1 *When price (or equivalently output) and capacity are both controlled by the network operator and the latter can use public funds to make transfers between consumers and the firm, no transport capacity is built (K=0) and pricing is such that:*

$$\frac{p_M - c}{p_M} = \frac{\lambda}{1+\lambda}\frac{1}{\eta(Q_M)} \tag{8}$$

The welfare function given in (5) will be strictly concave if, for any price-capacity couple $(p_M,\ K)$, the condition

$$(1+\lambda)C''(K)\left[(1+2\lambda)Q'_M + (1+\lambda)(p_M - c)Q''_M\right] < 0 \tag{9}$$

holds. As we have assumed $C''(K) > 0$ for any $K \geq 0$, provided $p_M \geq c$ (which is true), condition (9) is satisfied for any decreasing concave demand function such as the linear demand. Thus, in this case, the optimal price and capacity levels characterized by Proposition 1 are not only local but also global interior welfare maximizers.

[10]To minimize notation, the arguments of some of the demand and cost functions will be dropped in the presentation.

From equation (8) we see that pricing obeys a standard Ramsey principle according to which the price markup is inversely proportional to the price-elasticity of demand. It is indeed optimal to let the firm apply a markup since public funds are costly and transfers are allowed in this scheme.[11] Given that the participation constraint is binding, we note from (2) that the optimal transfer is equal to the difference between the (exogenous) fixed cost and the firm's variable profit. This transfer could be either positive of negative depending on the relative size of the fixed cost.

Let us illustrate the properties of this scheme in the case where demand is linear and the technology of capacity building is quadratic, i.e., exhibits decreasing returns to scale. More specifically, let

$$Q_M(p_M) = \gamma - p_M, \quad C(K) = \frac{\omega}{2}K^2; \quad \gamma, \omega > 0, \quad \gamma > c \tag{10}$$

Solving (6) and (7), and using (2) to derive the transfer, yields

$$p_M = c + \left[\frac{\lambda}{1+2\lambda}\right](\gamma - c) \tag{11}$$

$$K = 0 \tag{12}$$

with the associated monopoly output and transfer

$$q_m = \left[\frac{1+\lambda}{1+2\lambda}\right](\gamma - c) \tag{13}$$

$$T = F_m - \left[\frac{\lambda(1+\lambda)}{(1+2\lambda)^2}\right](\gamma - c)^2 \tag{14}$$

Condition (9) here takes the form $-\omega(1+\lambda)(1+2\lambda) < 0$, and the solution described by (11) and (12) is a global welfare maximizer. To illustrate the

[11]Below, we will show by means of an example that this Ramsey-type price structure comes to dominate marginal-cost pricing from a social welfare viewpoint.

optimality of this policy, let us compare its welfare level, $\widehat{W}$, to that of the alternative solution in which price is set to marginal cost, no capacity is built and a transfer is made to the local monopoly to cover its fixed cost, $\overline{W}$. We find that

$$\widehat{W} = \left[\frac{(1+\lambda)^2}{2(1+2\lambda)}\right](\gamma - c)^2 - (1+\lambda)F_m \tag{15}$$

$$\overline{W} = \frac{1}{2}(\gamma - c)^2 - (1+\lambda)F_m \tag{16}$$

and verify that $\widehat{W} \geq \overline{W}$ for any $\lambda \geq 0$. This example shows that, because of the existence of a positive cost of public funds and the possibility of using transfers, it is optimal to let the firm earn a markup even in the case where there are no fixed costs ($F_m = 0$).

Observe from (14) that the network operator can use the transfer either to tax the firm's profits if those are positive (this is the case when the fixed cost is smaller than variable profits), or to subsidize the firm otherwise (when the fixed cost is larger than variable profits). The fact that $\partial T/\partial\lambda$ $(= -[(\gamma - c)^2/(1+2\lambda)^3]) \leq 0$ should be interpreted as, when the cost of public funds λ increases, the size of the subsidy (tax) decreases (increases) conditionally on the constraint of fixed cost recovery.

4 Controlling the local monopoly with price and capacity only

We now assume that the network operator can still set the capacity and price levels but doesn't have the additional ability to make any transfer between consumers and the firm.[12]

Social welfare W is now expressed as

$$
\begin{aligned}
W = \;& S(Q_M(p_M)) - p_M Q_M(p_M) \\
& +(1+\lambda)\left[(p_M - c)K - C(K)\right] \\
& +(p_M - c)\left[Q_M(p_M) - K\right] - F_m
\end{aligned}
\tag{17}
$$

that is, as the sum of the net consumer surplus, the social value of the profits generated by the K units imported under competitive conditions, and the profits of the firm that now are not taxed. Gathering terms, we obtain

$$
\begin{aligned}
W = \;& S(Q_M(p_M)) + \lambda p_M K \\
& -(1+\lambda)\left[cK + C(K)\right] - c\left[Q_M(p_M) - K\right] - F_m
\end{aligned}
\tag{18}
$$

Cross-examining (5) and (18), we see that as he now cannot use transfers to collect firm's profits, the network operator assigns a fiscal value only to the revenue (and the cost) of the K units that are provided competitively.

Maximizing social welfare given by (18) with respect to price and capacity, under the participation constraint that now does not include transfers, yields the following first-order conditions:

$$(p_M - c)(1+\phi)Q_M' + \phi(Q_M - K) + \lambda K = 0 \tag{19}$$

$$(p_M - c)(\lambda - \phi) - (1+\lambda)C'(K) = 0 \tag{20}$$

$$\phi[(p_M - c)(Q_M - K) - F_m] = 0 \tag{21}$$

where ϕ is the Lagrange multiplier associated with the firm's participation

[12] In the next section, we consider the case where, in addition to not being able to use transfers, the network operator looses the ability to control price.

constraint. Note from (20) that $p_M \geq c$ and $C^{'}(K) \geq 0$ imply $\lambda \geq \phi$.[13]

The next proposition rewrites these conditions in a form that is somewhat comparable to the solution described in Proposition 1.

Proposition 2 *When price (or equivalently output) and capacity are both controlled by the network operator but the latter cannot use public funds to make transfers between consumers and the firm, optimal price and capacity satisfy the following conditions:*

$$\frac{p_M - c}{p_M} = \left[\frac{\phi}{1+\phi} + \left(\frac{\lambda - \phi}{1+\phi}\right)\frac{K}{Q_M}\right]\frac{1}{\eta(Q_M)} \tag{22}$$

$$(p_M - c)(\lambda - \phi) = (1+\lambda)C'(K) \tag{23}$$

The second-order conditions, namely that the bordered Hessian is negative definite at a point (K, p_M), boil down to[14]

$$(1+\lambda)C''(K)\left[(Q_M - K) + (p_M - c)Q'_M\right]^2 - (p_M - c)\left[2(Q_M - K)(\lambda - \phi) + (p_M - c)\left((1+2\lambda)Q'_M + (1+\phi)(p_M - c)Q''_M\right)\right] > 0 \tag{24}$$

Condition (22) shows that the price markup is proportional to the share of imports in the total consumption of gas. The reason for this is, as the price increases, the social marginal valuation of capacity increases (see (20)). We further see from (22) that, as in the scheme with transfers analyzed in the previous section, the price markup is inversely proportional to the elasticity of demand, but here in a more sensitive way.[15]

[13] This reflects the fact that the benevolent network operator values the firm's participation constraint no more than he values public funds.

[14] Note that this condition will only be satisfied for particular cases.

[15] Indeed, note that $\frac{\lambda}{1+\lambda} \leq \frac{\lambda}{1+\phi} \leq \frac{\phi}{1+\phi} + \left(\frac{\lambda-\phi}{1+\phi}\right)\frac{K}{Q_M}$.

Adding $(1+\lambda)c$ to both sides of condition (23), we see that at the optimum, the social cost of the marginal unit of gas shipped from the competitive market just equals the social cost of having this unit produced by the local monopoly plus the social opportunity cost of the profitability for the firm of this unit net of the value the network operator assigns to the contribution of this unit to the relaxation of the firm's participation constraint.

Compared to the case with transfers in which the capacity equation (7) can be rewritten as $(1+\lambda)c = (1+\lambda)(c+C'(K))$, there is an additional term, $(\lambda - \phi)(p_M - c)$, which is the "net" social valuation of the monopoly profits generated by an additional unit produced locally. Indeed, these profits can no longer be collected by the network operator as he now lacks the instrument that would allow him to do so.

As to the specific nature of the solutions associated with this no-transfer scheme, note up front that condition (20), by itself, since its left-hand side member is equal to the difference between two nonnegative terms, suggests that the system given by the first-order conditions (19)-(21) has alternative candidate solutions depending on the (demand and cost) parameters of the model. Let us refine our analysis of those solutions by considering the case with no fixed cost ($F_m = 0$) and with fixed costs ($F_m > 0$) in turn. The next theorem deals with the no-fixed cost case.

Theorem 1 *When price (or equivalently output) and capacity are both controlled by the network operator but the latter cannot use public funds to make transfers between consumers and the firm, and the firm has no fixed costs ($F_m = 0$), there are two exclusive candidate optimal policies (K, p_M, ϕ):*

(i) *The policy* $(0, c, 0)$ *which consists in building no capacity, setting price in the local market at marginal cost, and thus making the local monopoly just break even.*

(ii) *The policy* $(0 < K \leq Q_M, p_M > c, \phi \geq 0)$ *which prescribes building capacity and setting price above marginal cost. This policy takes one of the two following forms:*

(a) *The policy* $(0 < K < Q_M, p_M > c, 0)$ *in which the local monopoly meets part of the market demand and makes positive profits, resulting in a non-binding participation constraint.*

(b) *The policy* $(Q_M, p_M > c, \phi > 0)$ *in which the local monopoly is shut down and the whole market demand is met by imports.*

When $(1+\lambda)Q'_M C''(0) + \lambda^2 < 0$*, policy (i) is the optimal policy. When this condition does not hold, two situations might arise according to whether or not* $Q'_M \left[C''(K) - \dfrac{C'(K)}{K}\right] - \dfrac{\lambda K}{Q'_M} Q''_M C''(K) < 0$*. If this condition holds, then policy (ii-a) is the optimal policy. Otherwise, (ii-b) is.*

Proof 1 *Let us first check that policies (i), (ii-a) and (ii-b) are indeed candidate solutions for this control scheme, i.e., that they are local constrained social welfare maximizers. Given that* $C'(0) = 0$ *and* $F_m = 0$*, and since* $(1+\lambda)C''(0)Q_M^2 > 0$*, it is straightforward to show that policy (i) satisfies both the first- and second-order conditions (19)-(21) and (24).*

Policy (ii-a) will meet the first-order conditions when $(1+\lambda)Q'_M C'(K) + \lambda^2 K = 0$*. As this policy corresponds to an interior solution (the partici-*

pation constraint is not binding), the second-order condition reduces to[16]

$$(1+\lambda)\left[Q'_M + (p_M - c)Q''_M\right] C''(K) + \lambda^2 < 0$$

Below, we will see that when a policy of this type gets chosen, it indeed satisfies this second-order condition.

Policy (ii-b) will satisfy the first-order conditions when

$$\lambda(\lambda - \phi)Q_M + \ (1+\lambda)(1+\phi)C'(Q_M)Q'_M = 0$$

As to the second-order condition (24), policy (ii-b) satisfies it since

$$\frac{(\lambda Q_M)^2}{(1+\phi)^2 {Q'_M}^3}\left[{Q'_M}^2\left[(1+\lambda)Q'_M C''(Q_M) - (1+2\lambda)\right] + \lambda Q_M Q''_M\right] > 0$$

provided demand is concave and capacity building cost is convex.[17]

Let us now examine the process by which the optimal policy is chosen. In order to do so, we first study the unconstrained maximization program of the social welfare function (18) and then the firm's participation constraint.

The first and second-order conditions of the unconstrained social welfare maximization problem are, respectively,

$$\lambda K + (p_M - c)Q'_M = 0 \tag{25}$$

$$\lambda(p_M - c) - (1+\lambda)C'(K) = 0 \tag{26}$$

$$(1+\lambda)\left[Q'_M - \frac{\lambda K}{Q'_M}Q''_M\right] C''(K) + \lambda^2 < 0 \tag{27}$$

[16] In fact, this condition is the one guaranteeing that the Hessian of the social welfare function (18) be negative definite at this solution point.

[17] The latter condition is obtained by, substituting $(p_M - c)$ from either (19) or (20) in (24).

The level curves associated with the social welfare function (18), when represented in the $\{K, p_M\}$ *space, have a slope*

$$m_W = -\frac{\partial W/\partial K}{\partial W/\partial p_M} = -\frac{\lambda(p_M - c) - (1+\lambda)C'(K)}{\lambda K + (p_M - c)Q'_M} \tag{28}$$

Observe that the first-order condition (25) represents, in an implicit form, the set of capacity-price pairs for which the welfare level curves have an infinite slope. This set can be characterized by as a price function $\widetilde{p}_M(K) = c - \lambda K/Q'_M$*. Similarly, (26) represents the set of capacity-price pairs for which the welfare level curves have a zero slope and this set can be represented by* $\widehat{p}_M(K) = c + (1+\lambda)C'(K)/\lambda$*. Note that these two price functions cross at the point* $(K, p_M) = (0, c)$ *which need not, however, be the unique crossing point.*[18] *Let us characterize, if there are any, alternative crossing points.*

The slopes of these two price functions are given, respectively, by [19]

$$\frac{d\widetilde{p}_M}{dK} = -\frac{\lambda Q'_M}{{Q'_M}^2 - \lambda K Q''_M}$$

$$\frac{d\widehat{p}_M}{dK} = \frac{(1+\lambda)C''(K)}{\lambda}$$

Given concavity of demand and convexity of the capacity building cost function $C(.)$*, both of these functions have a nonnegative slope. Furthermore, provided that the regularity conditions* $Q'''_M \leq 0$ *and* $C'''(K) \geq 0$ *are satisfied, the function characterizing the points at which the welfare level curves have an infinite (a zero) slope is increasing concave (increasing convex). Hence, there exists at most one additional point at which the two price functions cross.*[20]

[18] Note that the first-order conditions (25) and (26) are satisfied at the points where these two price functions $\widetilde{p}_M(.)$ and $\widehat{p}_M(.)$ intersect.

[19] These slopes are obtained by totally differentiating the respective price functions.

[20] Such an additional crossing point does not exist when the two price functions are linear (see below for an illustration).

When demand is strictly concave and/or cost is strictly convex, the two price functions cross twice, and clearly the concave function, $\widetilde{p}_M(K)$, is steeper (flatter) than the convex function, $\widehat{p}_M(K)$, at the first (second) crossing point.[21] *Hence, setting $\widetilde{p}_M(K) = \widehat{p}_M(K)$ and $d\widetilde{p}_M/dK < d\widehat{p}_M/dK$, shows that the second crossing point satisfies*

$$\lambda^2 K + (1+\lambda) Q'_M C'(K) = 0 \tag{29}$$

$$(1+\lambda)\left[Q'_M - \frac{\lambda K}{Q'_M} Q''_M\right] C''(K) + \lambda^2 < 0 \tag{30}$$

Noting that (29) is a combination of (25) and (26) and that (30) is the same as (27), we see that such a second crossing point is an unconstrained welfare maximizer.

So far, we have established that in the case where the two price functions cross twice, the second intersection point is an unconstrained welfare maximizer. The next step is to find the conditions under which this second crossing point is $(0, c)$. This will also allow us to derive the conditions under which it is not $(0, c)$ that is the second crossing point but another point $(K > 0, p_M > c)$, in which case the latter is an unconstrained welfare maximizer.

When $(0, c)$ is the second crossing point, we see from (29) and (30) that it has to satisfy

$$(1+\lambda) Q'_M C''(0) + \lambda^2 < 0 \tag{31}$$

Consequently, if (31) does not hold, $(0, c)$ is the first crossing point and the

[21] The terms "first" and "second" are used here to merely indicate that one point (the first) is at the left of the other (the second).

second crossing point with $K > 0$ satisfies

$$Q'_M \left[C''(K) - \frac{C'(K)}{K} \right] - \frac{\lambda K}{Q'_M} Q''_M C''(K) < 0 \tag{32}$$

found by substituting λ^2 from (29) into (30).[22]

When both concavity of demand and convexity of cost are not strict, i.e., demand is linear and cost is quadratic, the two price functions cross once, at the point $(0, c)$, and either of these two functions can be steeper than the other. However, the crossing point $(0, c)$ is an unconstrained welfare maximizer when (31) holds, i.e., when $\widehat{p}_M(K)$ is steeper than $\widetilde{p}_M(K)$.

Now that we have analyzed the behavior of the social welfare function and characterized its unconstrained maximum, let us incorporate into the analysis the participation constraint given by

$$U = (p_M - c) \left[Q_M(p_M) - K \right] \geq 0 \tag{33}$$

The boundary of the set of points satisfying this participation constraint (the participation set), $\overline{U}$ (defined by $U = 0$), has a slope in the $\{K, p_M\}$ space given by

$$m_{\overline{U}} = -\frac{\partial U / \partial K}{\partial U / \partial p_M} = \frac{(p_M - c)}{(Q_M - K) + (p_M - c) Q'_M} \tag{34}$$

and this boundary will be flat whenever $p_M = c$ and will be decreasing concave, with a negative slope equal to $1/Q'_M$ when $p_M > c$ and $K = Q_M$ on this negatively-slopped portion of the boundary.[23]

[22] Examples of demand and cost that satisfy this condition are the linear demand combined with a capacity building cost function of the form $C(K) = (\omega/3)K^3$ or $C(K) = \omega K^2 \log[K]$.

[23] The concavity of the boundary of the participation set when it is decreasing is obtained by totally differentiating $m_{\overline{U}}$ and replacing $K = Q_M$.

Our discussion can now be summarized as follows. When $(0, c)$ *is a second crossing point of the price functions* $\widetilde{p}_M(.)$ *and* $\widehat{p}_M(.)$*, i.e., when (31) holds, it is an unconstrained welfare maximizer. Moreover, since it belongs to the participation set (more specifically, to the flat portion of its boundary), this point is also a constrained social welfare maximizer which says that policy (i) is optimal. If* $(0, c)$ *is a first crossing point, i.e., if (31) does not hold, then a second crossing point may or may not exist. If a second crossing point exists, (32) holds and the policy* $(0 < K < Q_M, p_M > c, 0)$*, namely policy (ii-a) is optimal.*[24] *Finally, if such a second crossing point does not exist, (32) does not hold and policy (ii-b), i.e.,* $(Q_M, p_M > c, \phi > 0)$ *which lies on the negatively-slopped portion of the boundary of the participation set is optimal.*

This completes the proof of Theorem 1.

To illustrate Theorem 1, let us consider two examples of functional forms: one that yields the couple of candidate optimal policies $\{(K = 0, p_M = c), (K = Q_M, p_M > c)\}$ and another that yields the couple $\{(K = 0, p_M = c), (K < Q_M, p_M > c)\}$. The first example goes back to the linear demand and quadratic capacity building cost function specification described in (10). In this case, the functions $\widetilde{p}_M(K)$ and $\widehat{p}_M(K)$ are straight lines and hence will cross only once at $(0, c)$. However, two cases need to be considered according to the relative magnitude of their slopes.

If $\omega(1 + \lambda) - \lambda^2 > 0$ (corresponding to (31)), the slope of the line rep-

[24]The reader should note that the nature of condition (32) is that when it holds, it guarantees simultaneously the existence of this policy and the fact that it satisfies second-order conditions of the unconstrained social welfare maximization program.

resenting the pairs where the level curves have infinite slope (λ), is smaller than that at which they are flat ($\omega(1+\lambda)/\lambda$). In this case, the welfare level curves are ellipses with social welfare increasing inwards, i.e., the closer we get to $(0, c)$. In this latter case, the point at which no capacity is built and price is set to marginal cost is the unconstrained welfare maximizer and will also solve (19)-(21). See Figure 2. Hence, the solution obtained is

$$p_M = c \tag{35}$$

$$K = 0 \tag{36}$$

$$\phi = 0 \tag{37}$$

namely, policy (i), with the associated monopoly output and social welfare

$$q_m = \gamma - c \tag{38}$$

$$W = \frac{1}{2}(\gamma - c)^2 \tag{39}$$

If $\omega(1+\lambda) - \lambda^2 < 0$ (corresponding to (31) not holding), we have that $d\widetilde{p}_M/dK > d\widehat{p}_M/dK$ and then welfare level curves will be of a hyperbolic shape with social welfare increasing outwards, i.e., the farther we get from the point $(0, c)$. See Figure 3. Given that (32) does not hold, from Theorem 1, policy (ii-b) is optimal. Indeed, solving (19)-(21) we find

$$p_M = c + \left[\frac{\lambda + \omega(1+\lambda)}{(1+2\lambda) + \omega(1+\lambda)}\right](\gamma - c) \tag{40}$$

$$K = \left[\frac{1+\lambda}{(1+2\lambda) + \omega(1+\lambda)}\right](\gamma - c) \tag{41}$$

$$\phi = \left[\frac{\lambda(1+\lambda)}{\lambda + \omega(1+\lambda)}\right] - 1 \tag{42}$$

yielding monopoly output and social welfare given by[25]

$$q_m = 0 \tag{43}$$

$$W = \left[\frac{(1+\lambda)^2}{2(1+2\lambda+\omega(1+\lambda))} \right] (\gamma - c)^2 \tag{44}$$

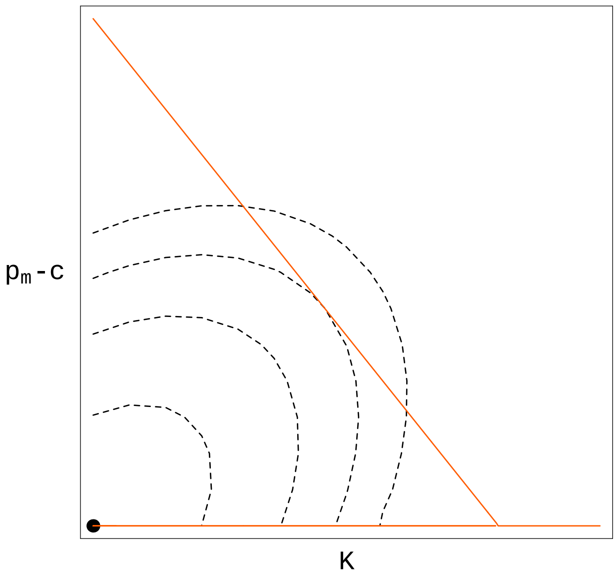

Figure 2: Solution with $F_m = 0$ and $\omega(1+\lambda) - \lambda^2 > 0$

[25]The reader may check that if $\omega(1+\lambda) - \lambda^2 < 0$, the level of social welfare given by (44) is indeed greater than that given by (39).

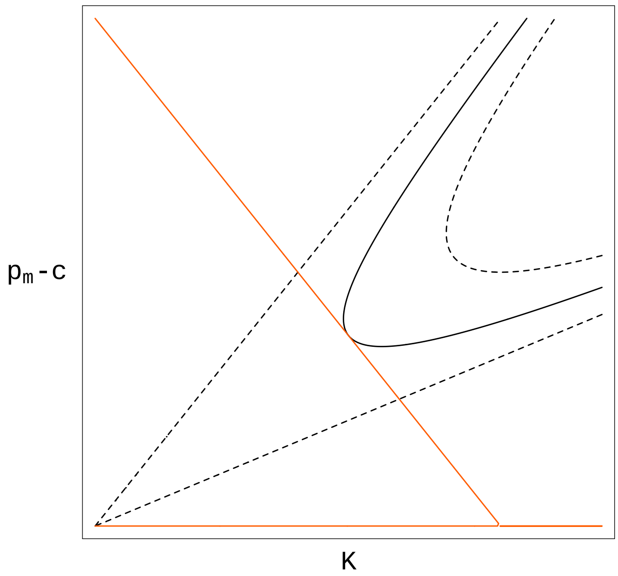

Figure 3: Solution with $F_m = 0$ and $\omega(1+\lambda) - \lambda^2 < 0$

The second example we consider is with a concave demand and a quadratic capacity building cost function, namely,

$$Q_M(p_M) = \gamma - \frac{1}{2}p_M^2, \quad C(K) = \frac{\omega}{2}K^2; \quad \gamma, \omega > 0 \tag{45}$$

Applying Theorem 1, yields that if $\lambda^2 - c\omega(1+\lambda) < 0$, policy (i) in which $p_M = c$, $K = 0$, and $q_m = \gamma - c$ is the optimal policy. Otherwise, since in this case (32) holds, the following policy (ii-a) turns out to be optimal[26]

$$p_M = \frac{\lambda^2}{\omega(1+\lambda)} \tag{46}$$

$$K = \frac{\lambda\left(\lambda^2 - c\omega(1+\lambda)\right)}{\omega^2(1+\lambda)^2} \tag{47}$$

$$q_m = \gamma - \frac{2\lambda\left[\lambda^2 - c\omega(1+\lambda)\right] + \lambda^4}{2\omega^2(1+\lambda)^2} \tag{48}$$

[26]Condition (32) here takes the form $\lambda\omega K/p_M > 0$.

Let us now turn to the case with $F_m > 0$. In this case, a casual look at (21), shows that the capacity-price pair $(0, c)$ does not belong to the participation set, and any candidate solution to the first-order conditions (19)-(21) will always yield a positive import capacity and a price above marginal cost.

The participation constraint now takes the form

$$U = (p_M - c)\left[Q_M(p_M) - K\right] - F_m \geq 0 \tag{49}$$

and the slope of its boundary

$$m_{\overline{U}} = \frac{(p_M - c)^2}{F_m + (p_M - c)^2 Q'_M} \tag{50}$$

which shows that this boundary has a positively sloped (convex) portion when the condition $F_m + (p_M - c)^2 Q'_M > 0$ holds, and a negatively sloped (concave) portion when this condition does not hold. Figure 4 shows the form of this boundary and how it varies with increasing F_m (starting from $F_m = 0$) for the case of linear demand.

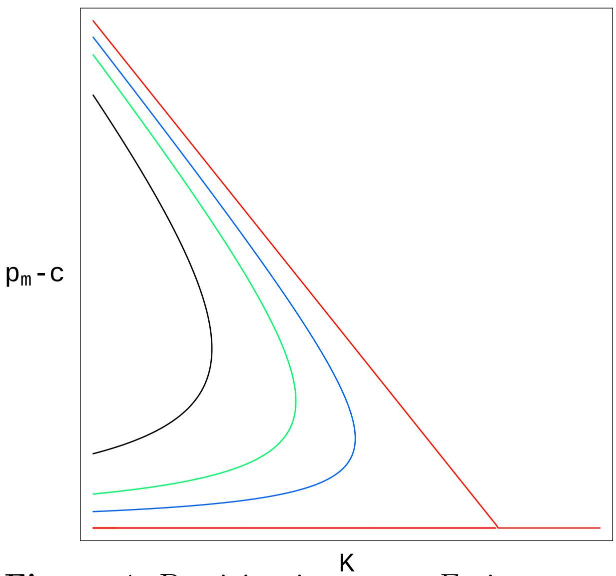

Figure 4: Participation set as F_m increases

Because of this relationship between the participation set and the magnitude of the fixed cost, we found the approach followed in the proof of Theorem 1 not conclusive, and hence we relied on an alternative approach.[27] Our attempt to obtain, in the case of $F_m > 0$, a closed-form solution under the demand and cost specification described by (10) was also not successful. Consequently, we relied on simulations under this specification to study the behavior of the endogenous variables of this scheme, namely, p_M, K, and ϕ. Using the values $\gamma = 10$ and $c = 2$, Figures 5a-6c show the outcome of these simulations the control parameter of which is the size of the fixed cost.

[27] In fact, the approach leads to an "indeterminacy." To be somewhat more specific, one of the problems come from the fact that capacity levels corresponding to tangency points (between social welfare level curves and the boundary of the participation set) in the negatively and positively sloped portions of the boundary of the participation set cannot be unambiguously ranked.

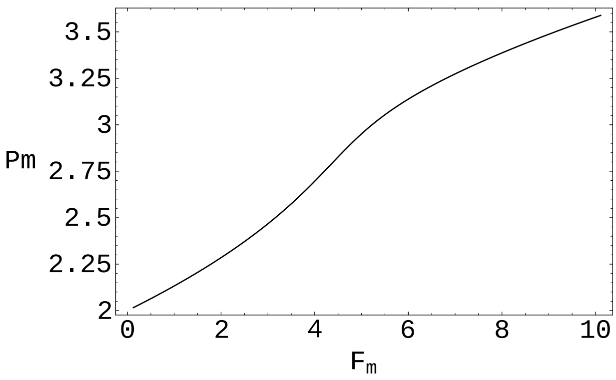

Figure 5a: Simulation of p_M with $F_m > 0$ and $\omega(1+\lambda) - \lambda^2 > 0$

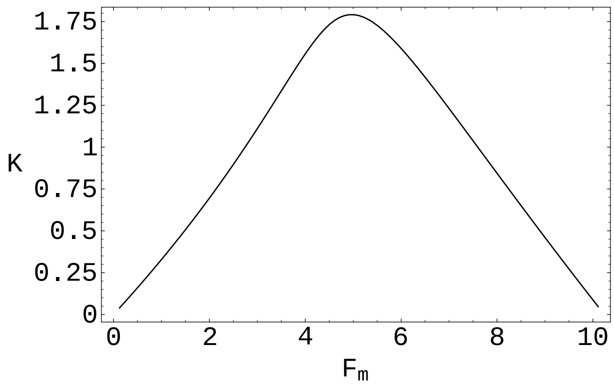

Figure 5b: Simulation of K with $F_m > 0$ and $\omega(1+\lambda) - \lambda^2 > 0$

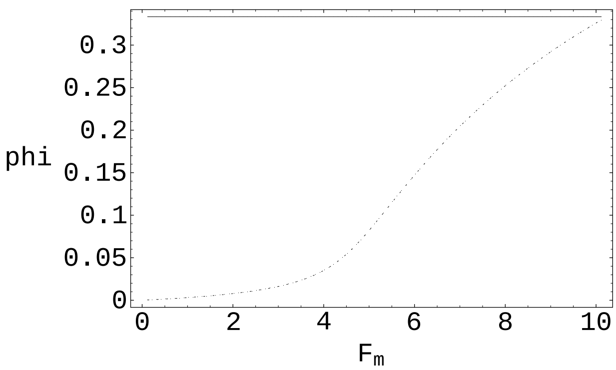

Figure 5c: Simulation of ϕ with $F_m > 0$ and $\omega(1+\lambda) - \lambda^2 > 0$ $\quad (\lambda = 1/3)$

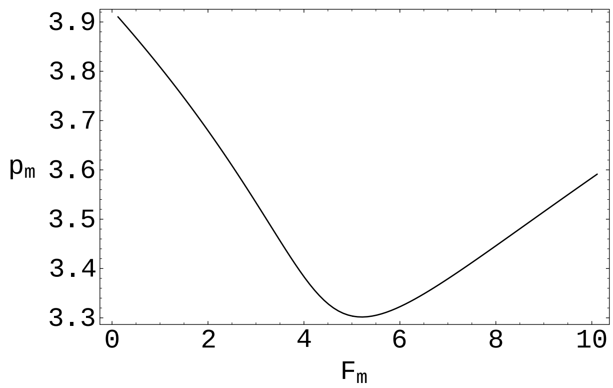

Figure 6a: Simulation of p_M with $F_m > 0$ and $\omega(1+\lambda) - \lambda^2 < 0$

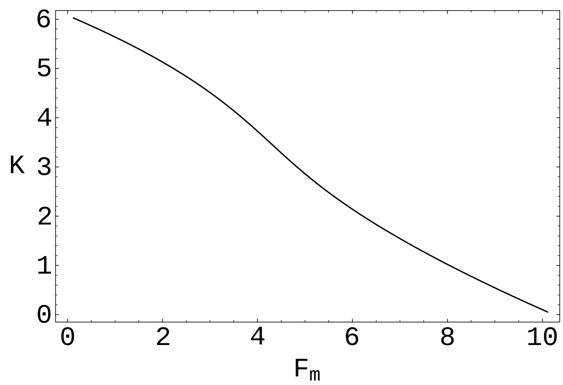

Figure 6b: Simulation of K with $F_m > 0$ and $\omega(1+\lambda) - \lambda^2 < 0$

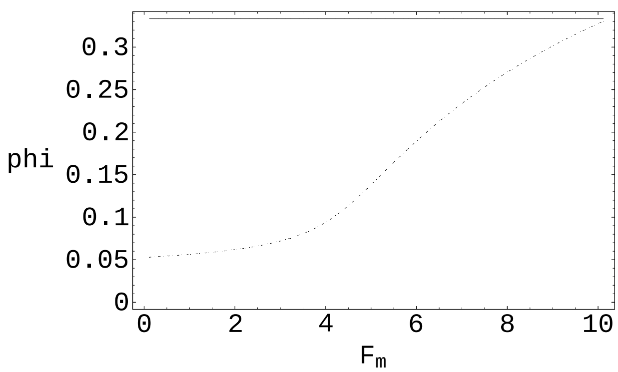

Figure 6c: Simulation of ϕ with $F_m > 0$ and $\omega(1+\lambda) - \lambda^2 < 0$ $\quad(\lambda = 1/3)$

The behavior of the optimum as F_m increases depends on the shape of the social welfare level curves, which itself depends on the sign of the polynomial $\omega(1+\lambda)-\lambda^2$. When this polynomial is positive (elliptical level curves), the tangency condition occurs in the region where both the welfare level curves and the boundary of the participation set $(\overline{U})$ are positively sloped. As F_m increases, these tangency points (see Figure 7) correspond to a monotonically increasing price (see Figure 5a) and an inverse U-shaped capacity (see Figure 5b).

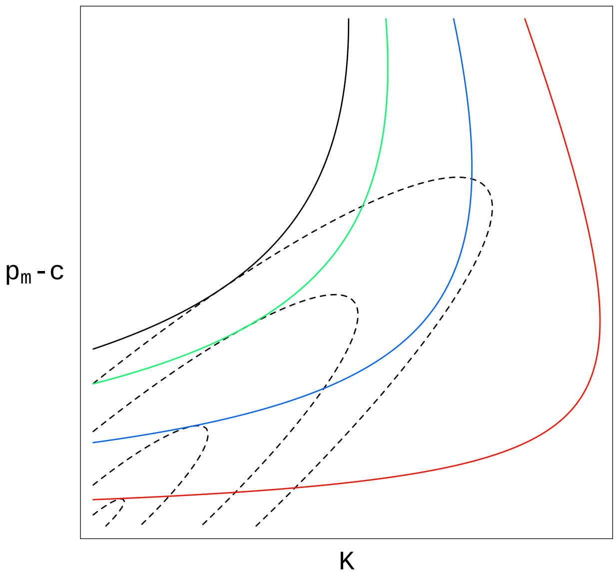

Figure 7: Tangency points as F_m increases when $\omega(1+\lambda)-\lambda^2>0$

When $\omega(1+\lambda)-\lambda^2<0$ (hyperbolic social welfare level curves), as F_m increases, the tangency condition occurs first in a region where both the level curves and $(\overline{U})$ are negatively sloped, and then in a region where they have a positive slope (see Figure 8). This leads to a U-shaped price (see Figure 6a) and a monotonically decreasing capacity (see Figure 6b). Figures 5c and 6c show that the shadow cost of the participation constraint, ϕ, gets increasingly closer to the cost of public funds λ as F_m gets larger.

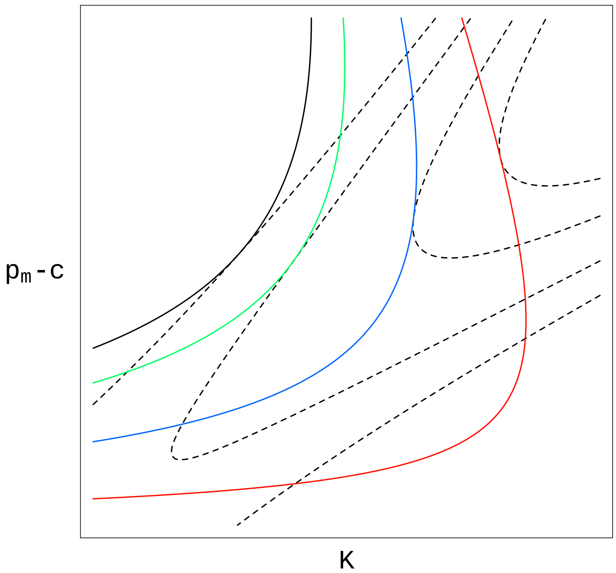

Figure 8: Tangency points as F_m increases when $\omega(1+\lambda) - \lambda^2 < 0$

5 Controlling the local monopoly with capacity only

In this section we assume that the network operator lacks an additional instrument of control of the regional monopoly activity, namely, pricing and can only use the level of capacity of the pipeline to counter its market power. In practice though, we model this case as if the network operator still continues to set the price level, but now this price has to fall within a constrained set of values. Let us be more specific.

For a given volume of gas K imported from the competitive market, the firm remains a monopoly in its local market on the residual demand

$Q_M(p_M) - K$ where p_M is price. Given this demand, the firm sets price so as to maximize its profit π^m given by

$$\pi^m = (p_M - c)\,[Q_M(p_M) - K] - F_m \tag{51}$$

The first-order condition of this profit-maximization problem is

$$(p_M - c)Q'_M + Q_M - K = 0 \tag{52}$$

while the second-order condition that ensures that we are indeed at a maximum is $2Q'_M + (p_M - c)Q''_M < 0$.

Given that transfers are not allowed, it is clear enough that the form of the social welfare function for this case is analogous to the one described in the previous section which we recall here:

$$\begin{aligned} W = \; & S(Q_M(p_M)) + \lambda p_M K \\ & -(1+\lambda)[cK + C(K)] - c[Q_M(p_M) - K] - F_m \end{aligned} \tag{53}$$

The optimization program that corresponds to this no-price control case requires then maximizing (53) with respect to p_M and K, under the constraint (52).[28]

Letting μ designate the Lagrange multiplier associated with the firm's profit-maximization constraint, we obtain the following first-order conditions:

$$(p_M - c)Q'_M + \lambda K - \mu\,\{2Q'_M + (p_M - c)Q''_M\} = 0 \tag{54}$$

$$\lambda(p_M - c) - (1+\lambda)C'(K) + \mu = 0 \tag{55}$$

$$(p_M - c)Q'_M + Q_M - K = 0 \tag{56}$$

[28] Strictly speaking, the second-order condition of the firm's profit-maximization program should also be taken as a constraint. The standard way to deal with this issue, however, is to check ex post that this second-order condition is satisfied by the solution to the optimization problem.

Rearranging terms allows us to state the following proposition:

Proposition 3 *When capacity only is controlled by the network operator, the following conditions are satisfied at the optimum:*

$$\frac{p_M - c}{p_M} = \lambda \frac{K}{Q_M} \frac{1}{\eta(Q_M)} - \frac{\mu}{\eta(Q_M)} \left\{ \frac{2Q'_M + (p_M - c)Q''_M}{Q_M} \right\} \tag{57}$$

$$(1+\lambda)c + \lambda(p_M - c) = (1+\lambda)[c + C'(K)] - \mu \tag{58}$$

$$(p_M - c)Q'_M + Q_M - K = 0 \tag{59}$$

The second-order conditions amount to[29]

$$(1+\lambda)C''(K)\left[2Q'_M + (p_M - c)Q''_M\right]^2 + \mu\left[3Q''_M + (p_M - c)Q'''_M\right] - \left[(1+4\lambda)Q'_M + (1+2\lambda)(p_M - c)Q''_M\right] > 0 \tag{60}$$

A few comments on the price and capacity conditions stated in this proposition are in order.

First, note that in this no-transfer scheme the price markup is again proportional to the cost of public funds in a more sensitive way than in the case analyzed above where the network operator could use transfers. Second, observe that, with respect to the case with price control, the price equation has an extra term the sign of which, assuming that the second-order condition of the firm's profit-maximization program holds, is the same as that of μ, the shadow cost of the profit-maximization constraint.

Finally, we see from (58) that, at the optimum, the social cost of having an extra unit produced locally by the monopoly, plus the social opportunity

[29]Note that for a downward-sloping linear demand, condition (60) holds for any value of μ, whereas for a strictly concave demand, it only holds for $\mu \leq 0$.

cost of the profit this unit generates for the firm, should be balanced against the social cost of importing this unit from the competitive region plus the cost of the violation of the profit-maximization constraint this imported unit induces. Note that $K = 0$ violates the first-order conditions (54)-(56) and hence is never optimal under scheme C.

Let us here too derive the solution of this scheme using the specification described in (10). Solving the first-order conditions (54), (55) and (52), we obtain[30]

$$p_M = c + \left[\frac{\lambda + 2\omega(1+\lambda)}{(1+2\lambda)(1+2\omega) + 2(\lambda+\omega)}\right](\gamma - c) \tag{61}$$

$$K = \left[\frac{1+2\lambda}{(1+2\lambda)(1+2\omega) + 2(\lambda+\omega)}\right](\gamma - c) \tag{62}$$

$$\mu = \left[\frac{\omega(1+\lambda) - \lambda^2}{(1+2\lambda)(1+2\omega) + 2(\lambda+\omega)}\right](\gamma - c) \tag{63}$$

with the corresponding monopoly output

$$q_m = \left[\frac{\lambda + 2\omega(1+\lambda)}{(1+2\lambda)(1+2\omega) + 2(\lambda+\omega)}\right](\gamma - c) \tag{64}$$

Note that the sign of the shadow cost of the firm's profit-maximization constraint, μ, will be that of the polynomial $\omega(1+\lambda) - \lambda^2$, a feature which will be further discussed in the next section.

6 The role of transport capacity: discussion

This section compares the three schemes analyzed in the previous section in terms of the levels of network transport capacity they prescribe. We first

[30] One can easily verify that the second-order condition (60) holds.

discuss the general case and then give results obtained for the specification described in (10).

For clarity of exposition we refer to the schemes described in section 3 (control of price and capacity with transfers), section 4 (control of price and capacity without transfers), and section 5 (control of capacity only) as schemes A, B, and C respectively. Let K^A, K^B, and K^C designate the associated optimal levels of network capacity.

For the purpose of comparing the capacity levels obtained under schemes A and B, let us recall here that from Proposition 1 the optimal policy to be followed under scheme A is to build no import capacity. As to scheme B, Theorem 1 tells us that when $F_m = 0$, optimal capacity may or may not be equal to zero. However, when $F_m > 0$ our discussion in section 4 suggested that building no capacity is never optimal. Hence, non-availability of transfers in scheme B leads to no less capacity than in the case where transfers are allowed (in scheme A). Hence, $K^A \leq K^B$.

Given that the social welfare function is the same under B and C, in order to compare the optimal capacity levels achieved under these alternative schemes, we analyze the relationship between the participation set and the set defined by the firm's profit-maximization constraint. By total differentiating the participation constraint, we see that the set of points at which its boundary is infinitely sloped coincides with the profit maximization set.[31]

If the point $(0, c)$ is an unconstrained welfare maximizer, the solution to the constrained welfare maximization program under scheme B will lie on

[31] Indeed, both of these sets can be seen to be defined by $p_M = c - (Q_M - K)/Q'_M$.

a tangency point where both the boundary of the participation set and the welfare level curves are positively sloped.[32] It is easy to see that such a point is strictly at the left of any tangency point on the profit-maximization set (under scheme C), and hence, $K^B < K^C$. If an unconstrained welfare maximizer does not exist, the solution to the constrained welfare maximization program under scheme B will correspond to a tangency point where both the boundary of the participation set and the welfare level curves are negatively sloped.[33] This point is strictly at the right of any tangency point on the profit-maximization set (under scheme C), and thus, $K^B > K^C$. Finally, if the point $(K > 0, p_m > c)$ is an unconstrained welfare maximizer, we cannot rank capacity outcomes.

A comparison of the capacity levels attained under schemes A and C is straightforward. In fact, a direct substitution into the first-order conditions associated with scheme C, (54)-(56), shows that $K = 0$ cannot be optimal. Hence, $K^C > 0$ and we conclude that the optimal import capacity obtained under scheme C is strictly greater than that under scheme A ($K^A < K^C$).

As an illustration, let us compare the capacity outcomes obtained under control schemes A, B, and C with the functional forms stated in (10) and $F_m = 0$. From the capacity levels obtained in (12), (36), (41), and (62), we can check that if $\omega(1 + \lambda) - \lambda^2 > 0$, then $0 = K^A = K^B < K^C$. Otherwise, i.e., if $\omega(1 + \lambda) - \lambda^2 < 0$, then $K^A < K^C < K^B$. This example shows that

[32]From the proof of Theorem 1, $(0, c)$ is an unconstrained welfare maximizer when (31) holds.

[33]From the proof of Theorem 1, an unconstrained welfare maximizer won't exist if conditions (31) and (32) do not hold, the latter being equivalent to demand being linear and capacity-building cost being quadratic.

the capacity ranking is not unambiguous.

Cremer and Laffont (2002) have directed attention to this ambiguity issue, although they have mainly focused on the "excess" capacity case by providing examples where the lack of price control leads to an over-sizing of the pipeline network. In this paper, we have further investigated this issue of network sizing by uncovering cases where network capacity and alternative instruments of market power control are both complements and substitutes. In contrast to Cremer and Laffont's study, our analysis allows us to identify situations of both over- and under-sizing of the network.

It is easy to see that Cremer and Laffont's comparison exercise is a special case of the comparisons we have performed in this paper. Indeed, setting $\lambda = 0$ in our modeling framework, we obtain scheme A as the first-best, and B and C reduce to the schemes considered by the authors in their comparison, namely, with and without price control. However, with $\lambda = 0$, in our framework, the case of under sizing is ruled out. For example, in the linear demand and quadratic capacity cost function specification (10), with $\lambda = 0$, the condition $\omega(1+\lambda) - \lambda^2 > 0$ holds, and hence we obtain $K^B < K^C$, i.e., "excess" capacity under scheme C where price is not controlled.

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