**The Welfare Effects of Unbundling
Gas Storage and Distribution**

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Abstract

We use a stylized gas system to study the use of access-to-gas storage in a seasonal model. In a duopoly setting, we find that welfare is higher under vertical integration and open access organisation than under separate management of storage and distribution. This raises questions about recent regulatory reforms in the gas sectors in the US and Europe, supporting the separation of storage and merchant activities. In the absence of other justifying reasons such as encouraging competition by creating a level playing field, separating the management and accounting functions of storage activities from those of distribution may be a better option than real divestiture, on the basis of welfare arguments.

Key Words: Gas market, equilibrium, open access.

Résumé

Nous analysons l'utilisation dans un duopole d'une installation de stockage de gaz en contexte saisonnier, dans un réseau de distribution stylisé. Deux architectures sont comparées. Dans la première, l'une des firmes opère l'installation de stockage et la rend disponible à son compétiteur. Dans la deuxième architecture, une troisième firme est responsable de l'opération de l'installation de stockage. Nous montrons dans ce modèle que le bien-être total est plus élevé dans la première architecture. Ceci soulève des questions au sujet des réformes réglementaires récentes dans le secteur du gaz aux USA et en Europe qui prônent la séparation des activités de stockage et de distribution.

1   Introduction

The natural gas industry has gone through dramatic changes in many countries. In the US for example, Order 636 etc. provoked tremendous modifications in the structure of the industry. The unbundling of merchant and transportation services helped create a more competitive environment, that discourages the concentration of market power (MacAvoy, 2000). Similar policies (for example, the new gas directive of 2003) were adopted in the EU.

Market power can take different aspects. A first example is the case of a pipeline monopolist, who can reduce capacity to increase profits. If the monopolist is also active in the downstream market (selling gas to customers), by imposing high transportation fees, he can increase his rivals' costs or even drive them out of the market. Another example is the use of storage as a competitive advantage. In markets with highly varying demand patterns, a storage facility plays an important arbitrage role, allowing to buy gas at low prices during low-demand periods in order to sell it at higher prices during high-demand periods. The owner of a storage facility can withdraw capacity to increase profits. Depending on the degree of seasonality and on the costs structures of competing firms, by imposing high storage fees, the owner of a storage facility can undercut any competitor who does not have access to gas storage, and drive him out of the market.

For downstream competitors, the pipeline and storage facilities are bottleneck or essential facilities[1] for transporting gas to the final markets. Open access to essential facilities was introduced to overcome this kind of market power. Within such a framework, the owner of an essential facility is mandated to give any entrant access to it, in exchange for payment. Regulated charges are widely used for such a purpose; however, auctions are increasingly being advocated as a superior alternative.

The aim of this paper is to analyze two market architectures, within a two-period model. The first architecture assumes an incumbent firm with a storage facility. The firm is mandated to give the entrant access to the facility upon request. Both firms compete in the downstream gas market. The second architecture assumes an independent storage provider. In both cases, the access fee is fixed by a regulator.

While it is well known, because of the double-marginalization argument, that an integrated monopolist is better than two monopolists in a vertical chain, the retail-market competition mechanisms for both architectures under consideration in this paper differ from those in standard competition models because of the Open Access framework, which introduces a Stackelberg competition component in the downstream market through the storage participation in the final goods offering.

The results of such an analysis can give some insight into the welfare merits of the unbundling policy recently adopted in many gas markets.

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[1] In network industries, bottleneck (or essential) facilities are defined as links, essential to reach the end buyers, for which there is no viable alternative.

This paper is organized as follows. Section 2 reviews some of the relevant literature on storage activity. Section 3 describes the model. Section 4 discusses the case of an incumbent both owning a storage facility and competing with and entrant in the final goods market. Section 5 discuses the case of an independent storage activity. Section 6 compares the two cases and reports on illustrative examples. Finally, Section 7 concludes.

2   The storage activity

The theory of storage for nonperishable goods goes back to Kaldor (1939). He shows that holding inventories helps to smooth production and profit from price fluctuations. Kirman and Sobel (1974) analyze inter-temporal price properties in an oligopolistic framework. Saloner (1987), Pal (1991, 1996) and Mollgaard, Poddar and Sasaki (2000) study the strategic role of storage in two-period Cournot models. They show that storage can be used as an advance production plan to affect rivals' future decisions. Arvan (1985) shows that the equilibrium in a model with stationary demand may be asymmetric in the case of linear storage costs. In a two-period game in which goods are produced in the first period and sold in the second period, Allaz (1991) shows that the two firms end up selling more than they would if storage were not allowed. Gaudet and Van Long (1996) show that a vertically integrated firm may increase the costs of its competitors by strategically buying an intermediate good. In a simultaneous game, Poddar and Sasaki (2002) emphasize the incentive for the firm to store. Thille (2003) studies the effects that the strategic use of inventories have on prices in a two-period model in which two firms compete a la Cournot. Again in a two-period Cournot model, Mitraille (2004) shows that symmetric inventories are more likely to prevail in an upturn market than in a downturn market.

The work which is closest to ours, studying the strategic use of storage in the gas industry, is that of Poudou et al. (2005). The authors study the strategic use of storage by considering an integrated firm operating in the upstream and downstream markets, and competing with a distribution company in the downstream market. The integrated firm sells gas (through its downstream component) to the final consumers and any surplus to the competing distribution firm. A storage facility is operated by a separate monopolist. The authors show that, while the integrated company produces gas upstream, there are still incentives for it to buy gas from the storage firm. This increases the demand for storage services and consequently impacts negatively on the competing distribution company. The authors also show that the integration of the storage services within the distribution company can alleviate this effect.

Our work differs in two main respects. First, we consider firms that operate in the downstream market only, in order to focus on the asymmetric endowment of facilities on this market: while the unbundling of the transportation and merchant functions has increased competition, it did not create a perfect competitive environment, some merchant firms were left with strategic assets, such as storage facilities, while others - along with some newcomers - do not have access to them because of high investment costs and scarcity

of suitable storage sites. Second, we consider the role played by the Open Access regime in the competitiveness of the downstream market.

3   The model

We consider two firms buying gas in a competitive market (wellhead) and contracting for transportation services with an independent pipeline company. The latter is operating a single pipeline, which connects the gas producers to the consumer market. A storage facility is located at the city gate (consumer market). This stylized system represents the physical gas market.

We consider a two-period model, where the two periods form the gas year. Period 1 is a low-price period while Period 2 is a high-price one. The storage facility is used for seasonal storage and not diurnal or peak-shaving storage. (Peak shaving storage is used for hedging activities on a daily or hourly basis). Seasonal storage facilities are filled during the low-price period and emptied during the high-price period.

We assume that the two firms compete in the downstream gas market and we study the two following market architectures:

1. One of the firms (the Incumbent) owns the storage facility and is mandated to give the other firm (the Entrant) access to it;
2. An independent third firm is responsible for the storage activity and sells storage services to the other two firms.

In both cases, pipeline ownership is separate from storage ownership, which allows us to isolate the storage effects.

The choice of these two architectures is justified by recent regulatory policies in the gas industry. Indeed, the unbundling of transportation and distribution services was to a large extent achieved in the last decade. However, many distribution firms were left with strategic assets (storage) while others - and new entrants - are at disadvantage. The new unbundling policies are aimed at ensuring a fair-competition environment by separating storage and distribution activities.

3.1   Downstream demand and upstream capacity

Demand in the downstream market is assumed to be linear and deterministic, so that the price in period t is given by

$$P_t = L_t - Q_t, t = 1, 2,$$

where Q_t is the quantity marketed in period t by the two firms. Normalizing the pipeline capacity to 1, we assume maximal demand to be higher than pipeline capacity in both periods, that is, $L_2 > L_1 \geq 1$.

We assume that the pipeline company is mandated by a regulatory agency to offer all of its available capacity through capacity rights; the two competing firms are thus endowed with capacity rights to access to the pipeline. We do not consider any strategic use of those rights.

We assume that the pipeline capacity constraint is binding in the second (high-demand) period, justifying the need for storage. As long as storage capacity is available, if the pipeline is used at full capacity in the second period, then distribution companies have incentives in storing gas in the first period in order to sell it in the second period at higher prices. In order to reflect the interrelations between storage and production decisions in the regulatory environment, players are provided with limited resources. We will be concentrating on the case where capacity in the low-demand period also becomes binding because of gas purchased and stored for the second period (quantities for storage compete with first-period demand for pipeline capacity), while storage capacity is large. This assumption reflects "high" seasonality in demand, and investments and operational policies of pipeline companies, seeking to maximize assets' rentability. We will show that the binding-capacity assumption is also motivated by a total welfare argument with respect to access-to-storage fees.

Finally, we normalize the marginal cost at the wellhead to 0 during the two periods. The assumption of equal wellhead marginal costs in both periods is justified by the competitiveness of the upstream market, where production cost is not seasonal.

3.2   The game

During the first period, gas is shipped from the wellhead to the customers and to the storage facilities. In the second period, both firms withdraw gas from storage and deliver it to customers along with the gas shipped from wellheads via the pipeline. Market clearing is done at the end of each period.

In the first architecture, the Incumbent is required to let the Entrant store gas upon request, in exchange for payment (Open Access framework). Therefore, the two firms compete a la Stackelberg for storage (and marketed quantities), that is, the Entrant takes the reaction of the Incumbent into account to optimize his profit. In the second architecture, both firms have access to storage upon request, therefore competing à la Cournot for marketed quantities. In both architectures, storage payment is in the form of a fee proportional to the quantity of gas stored.

The access-to-storage fee is set by an independent regulator. In practice, a variety of considerations, such as, for instance, reasonable profits, competitiveness, efficiency, and preservation of market shares, are taken into account for the setting of access fees by the regulator. Rate-of-return regulation and price-cap regulation are widely used.

3.3   Notation

Let:

s_m: Storage of Firm m, $m = 1, 2$;

$S = s_1 + s_2$:   total storage activity;

q_{mt}:   Gas distributed by Firm m during period $t, t = 1, 2$;

α: Pipeline-capacity rights owned by Firm 1, $\alpha \in (0, 1)$;

$1 - \alpha$:   Pipeline-capacity rights owned by Firm 2;

C: Long-run marginal cost of storage, assumed constant;

F: Access fees to the storage facility; in both architectures, we assume $F \geq C$;

Π_m: Profit of Firm m during the two periods of the gas year.

Consumer surplus, denoted V, is given by

$$V = (L_2 - P_2)(q_{12} + q_{22} + s_1 + s_2) + (L_1 - P_1)(q_{11} + q_{21}),$$

and total welfare, denoted W, is given by

$$W = V + \sum_m \Pi_m,$$

where $m \in \{1, 2\}$ in the first architecture and $m \in \{1, 2, 3\}$ in the second architecture, and where Firm 3 is the independent storage firm.

Notice that if both firms were to decide to use all of their pipeline-capacity rights for distribution in each period (no storage), the price in each period would be $\rho_1 =: L_1 - 1$ and $\rho_2 =: L_2 - 1$ respectively, consumer surplus would be $\upsilon =: 2$ and total welfare would be $\omega =: L_1 + L_2$. In order to facilitate the interpretation of the equilibrium solutions, we define the auxiliary parameters:

$A =: L_2 - L_1 - C$, or "adjusted seasonality", defined as the difference in prices for a given marketed quantity according to the season, reduced by the marginal cost of storage. This parameter measures the profitability of the inter-temporal transfer for both players;

$D =: F - C$, or "storage margin", defined as the difference between storage access fees and marginal cost. This parameter measures the profitability of lending capacity for the owner of the storage facility;

$\pi_1 =: \alpha (L_1 + L_2 - 2)$, profit of Firm 1 during the two periods of the gas year if both firms use all their pipeline-capacity rights for distribution;

$\pi_2 =: (1 - \alpha) (L_1 + L_2 - 2)$, profit of Firm 2 if both firms use all their pipeline-capacity rights for distribution.

4 The case of an incumbent firm owning a large storage facility

In this model, we identify Firm 1 as the Incumbent and Firm 2 as the Entrant. We assume that pipeline capacity is binding in the second period. This implies the following:

$$
\begin{aligned}
q_{12} &= \alpha \\
q_{22} &= 1 - \alpha \\
P_2 &= L_2 - 1 - (s_1 + s_2).
\end{aligned}
\tag{1}
$$

In the first period, assuming that pipeline-capacity rights are binding and that both firms have incentives to store gas for the second period because of the high seasonality yields:

$$
\begin{aligned}
q_{11} &= \alpha - s_1 \\
q_{21} &= 1 - \alpha - s_2 \\
P_1 &= L_1 - 1 + s_1 + s_2.
\end{aligned}
$$

Total profits of the Incumbent and the Entrant are thus given by

$$
\begin{aligned}
\Pi_1 &= P_2(\alpha + s_1) - C(s_1 + s_2) + Fs_2 + P_1(\alpha - s_1) \\
      &= L_1(\alpha - s_1) + L_2(\alpha + s_1) - (2s_1 + C)(s_1 + s_2) + Fs_2 - 2\alpha \\
\Pi_2 &= P_2(1 - \alpha + s_2) - Fs_2 + P_1(1 - \alpha - s_2) \\
      &= L_1(1 - \alpha - s_2) + L_2(1 - \alpha + s_2) - 2s_2(s_1 + s_2) - Fs_2 - 2(1 - \alpha).
\end{aligned}
$$

Given s_2, the Incumbent maximizes his profit by choosing s_1, satisfying the following first-order condition (assuming an interior solution):

$$
L_2 - 4s_1 - 2s_2 - C - L_1 = 0
$$

or

$$
s_1 = \frac{1}{4}(A - 2s_2),
$$

where it is apparent that the quantity stored by the Incumbent is directly related to adjusted seasonality (or profitability) and inversely to the quantity stored by the Entrant (due to limited capacity).

Knowing that, the Entrant maximizes his profit, which is given by

$$
L_1(1 - \alpha - s_2) + L_2(1 - \alpha + s_2) - 2s_2\left(\frac{1}{4}(A - 2s_2) + s_2\right) - Fs_2 - 2(1 - \alpha)
$$

by choosing s_2, satisfying the following first-order condition (assuming an interior solution):

$$L_2 - L_1 - \frac{1}{2}A - 2s_2 - F = 0$$

or

$$s_2 = \frac{1}{4}(A - 2D),$$

where it is apparent that the quantity stored by the Entrant, taking into account the reaction of the Incumbent, is directly related to adjusted seasonality, that is, the profitability of the inter-temporal transfer, and inversely to the margin, that is, the fees collected by the Incumbent for the use of the storage facility by the Entrant.

The corresponding equilibrium prices, quantities, profits and consumer surplus are summarized below (see Appendix A for conditions on the parameter values under which this equilibrium is feasible), where the index b (for bundled) is used to indicate the case where the storage facility is owned by Firm 1.

$$
\begin{aligned}
s_1^b &= \frac{1}{8}(A + 2D) \\
s_2^b &= \frac{1}{4}(A - 2D) \\
S^b &= \frac{1}{8}(3A - 2D) \\
q_{11}^b &= \alpha - \frac{1}{8}(A + 2D) \\
q_{21}^b &= 1 - \alpha - \frac{1}{4}(A - 2D) \\
P_1^b &= \frac{1}{8}(3A - 2D) + \rho_1 \\
&= S^b + \rho_1 \\
P_2^b &= -\frac{1}{8}(3A - 2D) + \rho_2 \\
&= -S^b + \rho_2 \\
V^b &= \frac{1}{32}(3A - 2D)^2 + \upsilon \\
&= 2\left(S^b\right)^2 + \upsilon \\
\Pi_1^b &= \frac{1}{32}\left(12D(A - D) + A^2\right) + \pi_1 \\
\Pi_2^b &= \frac{1}{16}(A - 2D)^2 + \pi_2.
\end{aligned}
\tag{2}
$$

Thus, in the stylized network where Firm 1 is required to provide access to storage to its competitor at a regulated fee, the total storage is $S^b = \frac{1}{8}(3A - 2D)$, proportional to the

profitability of inter-temporal transfers, and inversely proportional to the profitability of the storage facility operation. At equilibrium, the use of storage by the distribution firms, with respect to a situation where pipeline is used at full capacity for distribution, smooths the prices in the gas year and is beneficial to consumer surplus and firm profits.

Now, consider the access fee set by the regulator. The total welfare is given by

$$
\begin{aligned}
W^b &= AS^b + \omega \\
&= \frac{1}{8} A \left(3A - 2\left(F - C\right)\right) + \omega,
\end{aligned}
\tag{3}
$$

and is maximized by setting the access fee as low as possible. The effect of reducing the access fee (or reducing the margin D) on the equilibrium solution is an increase in total storage, with a corresponding increase in inter-temporal transfer, increasing consumer surplus and profit of the Entrant, and decreasing profit of the Incumbent. A reduction in the access fee increases the demand for storage by the Entrant, resulting in a reduction of the use of storage by the Incumbent (due to capacity constraints). In the limit, if the access fee were very low, the Entrant would want to use all his pipeline-capacity rights to ship gas to the storage facilities instead of selling it in the first period, thus transferring all his distribution operation to the more profitable second period. Assuming that the access fee cannot be set below the marginal cost C, which would correspond to the Incumbent subsidizing the Entrant firm's storage, the access fee which maximizes total welfare is given by the following:

$$
F^b = \max \left\{ C; \frac{1}{2} \left(A + 2C\right) - 2(1 - \alpha) \right\},
\tag{4}
$$

where it is interesting to note that the optimal access fee would reduce to 0 either the profits of the storage operation, or the quantity distributed by the Entrant in the first period.

5   The case of an independent storage firm

In this case, instead of one of the two firms offering storage services, there is an independent firm (Firm 3) administrating such services. Under the assumption of binding pipeline capacity in both periods, the total profits of the incumbent, the entrant and the independent firm are given by

$$
\begin{aligned}
\Pi_1 &= P_2(\alpha + s_1) - Fs_1 + P_1(\alpha - s_1) \\
&= L_2 \left(\alpha + s_1\right) - 2\alpha - s_1 \left(2s_1 + 2s_2 + F\right) + L_1 \left(\alpha - s_1\right) \\
\Pi_2 &= P_2(1 - \alpha + s_2) - Fs_2 + P_1(1 - \alpha - s_2) \\
&= L_2 \left(1 - \alpha + s_2\right) - 2 + 2\alpha - s_2 \left(2s_1 + 2s_2 + F\right) + L_1 \left(1 - \alpha - s_2\right) \\
\Pi_3 &= (F - C)(s_1 + s_2)
\end{aligned}
$$

The second-period outcome is again given by (1). In the first period, the first-order conditions, under the assumption of binding pipeline capacity, are

$$s_1 = \frac{1}{4}(A - D - 2s_2)$$
$$s_2 = \frac{1}{4}(A - D - 2s_1).$$

where it is apparent that the storage demand of each player is proportional to adjusted seasonality minus margin, and that the two players compete symmetrically for the use of the storage facility. The simultaneous solution of these conditions yields the following equilibrium, where the index u (unbundled) indicates that the storage facility is owned by a third party (see Appendix B for conditions on the parameter values under which this equilibrium is feasible):

$$
\begin{aligned}
s_1^u &= s_2^u = \frac{1}{6}(A - D) \\
S^u &= \frac{1}{3}(A - D) \\
q_{11}^u &= \alpha - \frac{1}{6}(A - D) \\
q_{21}^u &= (1 - \alpha) - \frac{1}{6}(A - D) \\
P_1^u &= \frac{1}{3}(A - D) + \rho_1 \\
&= S^u + \rho_1 \\
P_2^u &= -\frac{1}{3}(A - D) + \rho_2 \\
&= -S^u + \rho_2 \\
V^u &= \frac{2}{9}(A - D)^2 + \upsilon \\
&= 2(S^u)^2 + \upsilon \\
\Pi_1^u &= \frac{1}{18}(A - D)^2 + \pi_1 \\
\Pi_2^u &= \frac{1}{18}(A - D)^2 + \pi_2 \\
\Pi_3^u &= \frac{1}{3}D(A - D).
\end{aligned}
\tag{5}
$$

Thus, in the stylized network where an independent firm provides the storage at a regulated fee, the total storage is $S^u = \frac{1}{3}(A - D)$, proportional to the profitability of intertemporal transfers reduced by the profitability of the storage facility operation. Again, the use of storage by the distribution firms at equilibrium, with respect to a situation where

pipeline is used at full capacity for distribution, smooths the prices in the gas year and is beneficial to consumer surplus and firm profits.

Finally, the total welfare is given by

$$
\begin{aligned}
W^u &= \omega + AS^u \\
&= \omega + \frac{1}{3}A\left(A + C - F\right),
\end{aligned}
\tag{6}
$$

a decreasing function of F; again, total welfare is maximized by setting the access fee as small as possible. The effect of reducing the access fee (or the margin D) on the equilibrium solution is an equal increase in the storage of both players, with a corresponding increase in inter-temporal transfer, increasing consumer surplus and profits of both distribution firms, and decreasing the profit of the independent storage firm. In the limit, if the access fee were very low, the firm with fewer pipeline-capacity rights would want to use all of these rights to ship gas to the storage facilities instead of selling it in the first period, thus transferring all its distribution operation to the more profitable second period.

The optimal access fee is given by the following:

$$
F^u = \max\left\{A + C - 6\alpha;\ A + C - 6(1 - \alpha);\ C\right\},
\tag{7}
$$

where we see that the optimal access fee would either reduce to 0 the profit from storage operations, or result in the firm with fewer pipeline-capacity rights transferring all its distribution operations to the more profitable second period.

Remark 1 *We assumed an interior solution in both architectures. Indeed, a set of parameters for which the quantity distributed in the first period or for which the market price would be null at equilibrium lacks realism.*

Remark 2 *In all our results, the driving assumption is that it is interesting for the firms to use storage (high seasonality with respect to the storage cost), justifying the use of a storage facility, while capacity constraints limit the inter-temporal transfers (otherwise, there is no strategic interaction between players).*

Remark 3 *We assumed that pipeline capacity is binding in both periods. It can be shown (see Appendix C) that, if such a feasible equilibrium exists for some access price, it provides a higher total welfare than any other equilibrium where the access price makes the pipeline capacity under-used at equilibrium. Thus, if total demand is sufficiently high, choosing an access price that will make the pipeline be under-used would reduce total welfare; and that motivates our assumption.*

6 Comparing the two architectures

In order to compare the two architectures, we assume that the margin for storage operation is non negative and that the problem parameters are such that both equilibrium solutions

are feasible. We compute the differences in total welfare and in consumer surplus at equilibrium for two situations: in the first, the access fee is the same in the two architectures; in the second, the access fee is different and is maximizing total welfare in each architecture.

Notice that the difference in total welfare and consumer surplus can be written as a function of differences in total storage:

$$
\begin{aligned}
V^b - V^u &= 2\left(S^b - S^u\right)\left(S^b + S^u\right) \\
W^b - W^u &= A\left(S^b - S^u\right).
\end{aligned}
$$

If total storage is higher in one architecture than in the other, then both consumer surplus and total welfare will also be higher for this architecture. Indeed, higher use of storage results in higher inter-period transfer and smoother prices across periods, which is welfare-enhancing.

6.1   Identical access fees

The difference in total storage is given by:

$$
S^b - S^u = \frac{1}{24}\left(A + 2D\right)
$$

which is non-negative using (9) and $D \geq 0$. As a consequence, if all parameters are equal, and access prices are the same, total welfare and consumer surplus are always larger in the case of bundled activities, with differences given by

$$
\begin{aligned}
W^b - W^u &= \frac{1}{24}A\left(A + 2D\right) \\
V^b - V^u &= \frac{1}{288}\left(17A - 14D\right)\left(A + 2D\right).
\end{aligned}
$$

Under identical conditions, the difference between the two architectures resides in the strategic position of the players with respect to the use of storage under limited resources. In the bundled case, since the Incumbent is required to provide access upon request, the Entrant uses this information and benefits from a larger relative share of the storage facility than in the other case under symmetric competition. It is interesting to note that this asymmetry gives rise to a higher total use of the strategic storage variable.

6.2   Optimal access fees

In this section, we investigate the various cases that can arise when the access fee optimizes welfare in each architecture. Optimal access fees are given in (4) and (7) respectively.

1. $F^u = F^b = C$

   This corresponds to the case where the optimal access fee results in no profit from the storage operation, in both architectures. This happens when the following conditions are satisfied simultaneously:

$$
\begin{aligned}
A &\leq 6\alpha \\
A &\leq 4(1-\alpha),
\end{aligned}
$$

   that is, when adjusted seasonality is relatively low. In this case, access fee is the same in the two architectures, the result obtained in the preceding section holds, and the bundled architecture gives higher total storage, consumer surplus and total welfare.

2. $F^b = C$ and $F^u = A + C - 6\left(1 - \alpha\right)$

   This situation is impossible, since it requires

$$
6\left(1 - \alpha\right) \leq A \leq 4\left(1 - \alpha\right).
$$

3. $F^b = C$ and $F^u = A + C - 6\alpha$

   This corresponds to a case where the optimal access fee results in no profit from the storage operation in the bundled case, while Firm 1 chooses to use all its pipeline-capacity rights for storage in the first period in the unbundled case. This happens when the following conditions are satisfied:

$$
\begin{aligned}
6\alpha &\leq A \leq 4\left(1 - \alpha\right) \\
\alpha &\leq \frac{1}{2},
\end{aligned}
$$

   that is, when Firm 2 (the Entrant) has more than half of the access rights and adjusted seasonality is not too high. Replacing the optimal access prices in the expressions for total storage yields

$$
S^b - S^u = \frac{1}{8}\left(3A - 16\alpha\right),
$$

   which is positive since $A \geq 6\alpha > \frac{16}{3}\alpha$. As a consequence, total welfare and consumer surplus are higher in the bundled case. Differences are given by

$$
\begin{aligned}
W^b - W^u &= \frac{1}{8}A\left(3A - 16\alpha\right) \\
V^b - V^u &= \frac{1}{32}\left(3A - 16\alpha\right)\left(3A + 16\alpha\right).
\end{aligned}
$$

4. $F^b = \frac{1}{2}\left(A + 2C\right) - 2(1 - \alpha)$ and $F^u = C$

   This corresponds to a case where the Entrant chooses to use all his pipeline-capacity rights for storage, distributing only in the second period in the bundled case, while

the profit of the storage operation is null in the unbundled case. This happens when the following condition is satisfied:

$$4(1 - \alpha) \leq A \leq 6\underline{\alpha},$$

where $\underline{\alpha} =: \min\{\alpha, 1 - \alpha\}$ represents the smaller of the two pipeline-capacity rights. In this case, adjusted seasonality is relatively high with respect to the Entrant's pipeline rights. Replacing , we obtain the following for the difference in total storage:

$$S^b - S^u = \frac{1}{12}\left(6\left(1 - \alpha\right) - A\right),$$

where $A \leq 6\left(1 - \alpha\right)$, showing that the bundled architecture gives higher total storage, consumer surplus and total welfare. Differences are given by:

$$
\begin{aligned}
W^b - W^u &= \frac{A}{12}\left(6\left(1 - \alpha\right) - A\right) \\
V^b - V^u &= \frac{1}{72}\left(7A + 6\left(1 - \alpha\right)\right)\left(6\left(1 - \alpha\right) - A\right).
\end{aligned}
$$

5. $F^b = \frac{1}{2}\left(A + 2C\right) - 2(1 - \alpha)$ and $F^u = A + C - 6\underline{\alpha}$

   This corresponds to a case where, in each architecture, one of the players (respectively the Entrant and the player with less pipeline-capacity rights) chooses to use all his rights for storage. This situation happens under the following conditions:

$$
\begin{aligned}
A &\geq 4(1 - \alpha) \\
A &\geq 6\underline{\alpha},
\end{aligned}
$$

that is, when the adjusted seasonality is high. Replacing, we get the following expression for the difference in total storage:

$$
\begin{aligned}
S^b - S^u &= \frac{1}{4}\left(A + 2\left(1 - \alpha\right) - 8\underline{\alpha}\right) \\
&\geq 2\left(\left(1 - \underline{\alpha}\right) - \alpha\right) \geq 0.
\end{aligned}
$$

Again, the bundled architecture results in higher total storage, total welfare and consumer surplus. Differences are given by:

$$
\begin{aligned}
W^b - W^u &= \frac{A}{4}\left(A + 2\left(1 - \alpha\right) - 8\underline{\alpha}\right) \\
V^b - V^u &= \frac{1}{8}\left(A + 2\left(1 - \alpha\right) - 8\underline{\alpha}\right)\left(A + 2\left(1 - \alpha\right) + 8\underline{\alpha}\right).
\end{aligned}
$$

We have shown that, in all possible cases, the bundled architecture leads to higher consumer surplus and total welfare than does the unbundled architecture. This result is follows from the strategic advantage which is given to the Entrant in the Open Access

framework. Because of this advantage, the Entrant is led to use a larger share of the storage resource, which in turn increases total storage, smooths prices across the gas year, and increases consumer surplus and profits.

Table 1 below gives the equilibrium solutions and welfare corresponding to examples illustrating all cases.

	Case 1		Case 3		Case 4		Case 5		Case 6	
	f=3.4	f^b=c f^u=c	f=0.2	f^b=c f^u=0.18	f=0.3	f^b=0.25 f^u=c	f=1.5	f^b=1.03 f^u=1.44	f=0.45	f^b=0.4 f^u=0.2
L_1	10	10	1.2	1.2	2	2	10	10	3	3
L_2	15	15	3	3	4	4	13	13	5.9	5.9
c	3	3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
α	0.4	0.4	0.27	0.27	0.6	0.6	0.74	0.74	0.45	0.45
s_1^b	0.350	0.250	0.238	0.213	0.288	0.275	0.713	0.595	0.438	0.425
s_2^b	0.300	0.500	0.375	0.425	0.375	0.400	0.025	0.260	0.525	0.550
q_{11}^b	0.050	0.150	0.033	0.058	0.313	0.325	0.028	0.145	0.012	0.025
q_{21}^b	0.300	0.100	0.355	0.305	0.025	0.000	0.235	0.000	0.025	0.000
P_1^b	9.650	9.750	0.813	0.838	1.663	1.675	9.738	9.855	2.963	2.975
P_2^b	13.350	13.250	1.388	1.363	2.338	2.325	11.263	11.145	3.938	3.925
Π_1^b	9.565	9.325	0.744	0.684	2.640	2.611	16.590	16.490	3.672	3.631
Π_2^b	13.890	14.050	1.747	1.787	1.741	1.760	5.461	5.528	4.071	4.098
CS^b	2.845	3.125	2.750	2.813	2.878	2.911	3.088	3.462	3.853	3.901
TW^b	26.300	26.500	5.241	5.284	7.259	7.283	25.139	25.480	11.595	11.630
s_1^u	0.267	0.333	0.267	0.270	0.283	0.317	0.250	0.260	0.408	0.450
s_2^u	0.267	0.333	0.267	0.270	0.283	0.317	0.250	0.260	0.408	0.450
q_{11}^u	0.133	0.067	0.003	0.000	0.317	0.283	0.490	0.480	0.042	0.000
q_{21}^u	0.333	0.267	0.463	0.460	0.117	0.083	0.010	0.000	0.142	0.100
P_1^u	9.533	9.667	0.733	0.740	1.567	1.633	9.500	9.520	2.817	2.900
P_2^u	13.467	13.333	1.467	1.460	2.433	2.367	11.500	11.480	4.083	4.000
Π_1^u	9.342	9.422	0.736	0.740	2.561	2.601	15.665	15.675	3.438	3.510
Π_2^u	13.942	14.022	1.748	1.752	1.761	1.801	5.585	5.595	4.128	4.200
Π_3^u	0.213	0.000	0.053	0.043	0.113	0.000	0.700	0.697	0.286	0.090
CS^u	2.569	2.889	2.569	2.583	2.642	2.802	2.500	2.541	3.334	3.620
TW^u	26.067	26.333	5.107	5.118	7.077	7.203	24.450	24.508	11.187	11.420
$CS^b - CS^u$	0.276	0.236	0.181	0.230	0.236	0.109	0.588	0.921	0.519	0.281
$TW^b - TW^u$	0.233	0.167	0.135	0.166	0.182	0.079	0.689	0.972	0.408	0.210

7   Conclusion

A two-period model of a stylized gas distribution network is used to analyze two common gas-market architectures. The case of an incumbent firm owning the storage facility and the case of an independent storage owner not participating in the final-goods market are analyzed in a duopoly competition framework. A regulator is setting the access-to-storage tariffs.

We consider the case where seasonality in prices and limited transportation capacity justify the need for storage and induce a strategic behavior by the players, storing gas during low demand period to sell it at higher prices during the high demand period. Under reasonable assumptions, we show that the use of storage in that context is welfare enhancing, smoothing the prices across periods and increasing consumer surplus.

We also show that in the case of an integrated firm owning the storage facilities and operating in the downstream market, the strategic advantage given by the Open Access framework to the Entrant induces a higher use of the storage facility, resulting finally in higher consumer surplus and total welfare. This corroborates a similar result obtained in Poudou et al. (2005), although in different market structures. These results can be useful in the debate about the separation of the storage and distribution functions in the gas chain.

8   Appendix

A. Conditions for equilibrium in the bundled-activities case For (2) to be an equilibrium, the following conditions must be satisfied:

All variables and prices are non-negative:

$$
\begin{align}
A &\geq -2D \tag{8} \\
A &\geq 2D \tag{9} \\
A &\leq -2D + 8\alpha \tag{10} \\
A &\leq 2D + 4(1 - \alpha) \tag{11} \\
3A &\geq 2D - 8(L_1 - 1) \tag{12} \\
3A &\leq 2D + 8(L_2 - 1) \tag{13}
\end{align}
$$

Profits are non-negative:

$$
\frac{1}{32}\left(12D(A - D) + A^2\right) + \alpha(L_1 + L_2 - 2) \geq 0 \tag{14}
$$

$$
\frac{1}{16}(A - 2D)^2 + (1 - \alpha)(L_1 + L_2 - 2) \geq 0. \tag{15}
$$

Also, we assumed that the pipeline is operated at full capacity in both periods. Using auxiliary variables $t_{i1} = q_{i1} + s_i$ and $t_{i2} = q_{i2}$ and

$$
\begin{aligned}
\Pi_1 &= P_2(s_1 + q_{12}) - C(s_1 + s_2) + Fs_2 + P_1(q_{11}) \\
&= (L_2 - s_1 - s_2 - q_{12} - q_{22})(s_1 + q_{12}) - C(s_1 + s_2) + Fs_2 + (L_1 - q_{11} - q_{21})(q_{11}) \\
\Pi_2 &= P_2(s_2 + q_{22}) - Fs_2 + P_1(q_{21}) \\
&= (L_2 - s_1 - s_2 - q_{12} - q_{22})(s_2 + q_{22}) - F(s_2) + (L_1 - q_{11} - q_{21})(q_{21}),
\end{aligned}
$$

this implies $\frac{\partial \Pi_1(q_{11}^b, q_{12}^b, q_{21}^b, q_{22}^b, s_1^b, s_2^b)}{\partial s_1} \geq 0$ and $\frac{\partial \Pi_1(q_{11}^b, q_{12}^b, q_{21}^b, q_{22}^b, s_1^b, s_2^b)}{\partial q_{12}} \geq 0$, or

$$
\begin{aligned}
L_2 - 2s_1^b - s_2^b - 2q_{12}^b - q_{22}^b &\geq C \\
L_2 - 2s_1^b - s_2^b - 2q_{12}^b - q_{22}^b &\geq 0
\end{aligned}
$$

which reduces to

$$
L_1 + L_2 - C \geq 2(1 + \alpha), \tag{16}
$$

and $\frac{\partial \Pi_2(q_{11}^b, q_{12}^b, q_{21}^b, q_{22}^b, s_1^b, s_2^b)}{\partial s_2} \geq 0$ and $\frac{\partial \Pi_2(q_{11}^b, q_{12}^b, q_{21}^b, q_{22}^b, s_1^b, s_2^b)}{\partial q_{22}} \geq 0$, or

$$
\begin{aligned}
L_2 - 2s_2^b - s_1^b - q_{12}^b - 2q_{22}^b &\geq F \\
L_2 - 2s_2^b - s_1^b - q_{12}^b - 2q_{22}^b &\geq 0
\end{aligned}
$$

which reduces to

$$
5L_1 + 3L_2 - 2F - C \geq 8(2 - \alpha). \tag{17}
$$

Condition (8) holds if $D \geq 0$ and (9) is satisfied. Condition (12) holds if $D \geq 0$, $L_1 \geq 1$, and (9) is satisfied. Conditions (13) and (15) hold if $L_1 \geq 1$ and $L_2 \geq 1$. Condition (14) holds if $L_1 \geq 1$ and $L_2 \geq 1$ and (9) is satisfied.

The equilibrium conditions in the bundled-activities case are therefore equivalent to conditions (9)-(11),(16)-(17).

The coefficient of F in (3) is $-\frac{1}{4}A$. Using (9) and $D \geq 0$ yields $A \geq 0$, so that W_b is a decreasing function of F and the optimal access fee, denoted F^b, is the minimal value such that conditions (9)-(11),(16)-(17) are satisfied, that is,

$$
F^b = \max\left\{ C; \frac{1}{2}(A + 2C - 4(1 - \alpha)) \right\}.
$$

B. Conditions for equilibrium in the unbundled-activities case Denote $\underline{\alpha} \equiv \min\{\alpha; 1 - \alpha\}$, then for (5) to be an equilibrium, the following conditions must be satisfied:

All variables and prices are non-negative:

$$
0 \leq A - D \leq 6\underline{\alpha} \tag{18}
$$

$$-3\left(L_1 - 1\right) \;\leq\; A - D \leq 3\left(L_2 - 1\right). \tag{19}$$

Profits are non-negative:

$$\frac{1}{18}\left(A - D\right)^2 + \underline{\alpha}\left(L_1 + L_2 - 2\right) \;\geq\; 0 \tag{20}$$

$$\frac{1}{3}D\left(A - D\right) \;\geq\; 0. \tag{21}$$

Pipeline operates at full capacity:

$$L_2 - 2s_1^u - s_2^u - q_{22}^u - 2q_{12}^u \;\geq\; F$$
$$L_2 - 2s_2^u - s_1^u - q_{12}^u - 2q_{22}^u \;\geq\; F,$$

which reduces to

$$L_1 + L_2 - F \geq 2\left(2 - \underline{\alpha}\right). \tag{22}$$

Condition (20) always holds if $L_2 > L_1 \geq 1$. Conditions (18) and $D \geq 0$ imply (21). Notice that condition (22) implies that $A - D + 2L_1 \geq 3$, so that condition (19) is redundant.

The equilibrium conditions in the unbundled-activities cases are therefore equivalent to conditions (18) and (22).

The coefficient of F in (6) is $-A$, which is negative using (18) and $D \geq 0$. Again, total welfare is decreasing in F and the optimal access fee, denoted by F^u, is the minimal value such that conditions (18) and (22) are satisfied, that is,

$$F^b = \max\left\{C; A + C - 6\underline{\alpha}\right\}.$$

C. Binding capacity assumption We assume that the demand potential is sufficiently high to justify using the full capacity of the pipeline at equilibrium. For instance, in the bundled case, a sufficient condition on the parameters of the model is

$$L_1 + L_2 - C \geq 4.$$

In that case, (16) is always satisfied and (17) is satisfied at equilibrium, using (10).

Notice that if there exists a set of parameters L_1, L_2, C, F, α satisfying conditions (9)-(11) and (16)-(17), then condition (16) is satisfied for any F and condition (17) can only be made tighter by increasing F, which would reduce total welfare.

In the unbundled case, a sufficient condition on the model parameters for the capacity constraint to be binding at equilibrium, is

$$L_1 + L_2 - F \geq 3.$$

Again, it is easy to see that if there exists a set of parameters L_1, L_2, C, F, α satisfying conditions (18) and (22), then condition (22) can only be made tighter by increasing F, which would reduce total welfare.

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