



FiME

LABORATOIRE COMMUN
DAUPHINE CREST EDF

LABORATOIRE DE FINANCE DES MARCHÉS DE L'ÉNERGIE



Real Asset Valuation Based on Spot Prices: Can We Forget about Market Fundamentals?

Corinne Chaton Laure Durand-Viel

**Rapport de Recherche
RR-FiME-10-04
Avril 2010**

Real Asset Valuation Based on Spot Prices: Can We Forget About Market Fundamentals?

Corinne Chaton
FIME, CABREE*

Laure Durand-Viel
Université Paris-Dauphine, CREST-LEI, France.†

April 30, 2010

Abstract

Real assets are usually valued by assuming a liquid spot market with competitive traders who buy or sell until arbitrage opportunities are exhausted; the value of a real asset is computed as the stream of profits resulting from such transactions. This method ignores market fundamentals by assuming that all the relevant information is included in the spot price. This paper analyses the bias resulting from such an approach when the market is imperfectly competitive. We propose a stylised model of the natural gas market with two types of oligopolistic players: pure traders and suppliers with downstream customers. We compute the trading valuation and the supplier valuation of storage capacity. Comparing the latter value with the value obtained under the traditional, price-taking assumption reveals a systematic bias that tends to induce under-investment.

1 Introduction

Commodity contracts can involve some flexibility with respect to both the timing and the amount of commodity delivered, especially in the electricity and natural gas markets. Such contracts allow their holders to repeatedly receive variable volumes, subject to daily, monthly and/or annual constraints,

*E-mail: corinne.chaton@edf.fr.

†E-mail : lauredv@gmail.com.

at a predetermined price, thereby incorporating options known as swing or take-or-pay options (see Thompson, 1995, for a description). The pricing of these options constitutes an active domain of research (see for example Barrera-Esteve et al., 2006; Jaillet et al., 2004; Carmona-Ludkovski, 2008). While these valuation techniques were primarily designed for the pricing of financial assets, their use has been extended to the valuation of real assets—such as production plants, pipelines or storage sites—that allow their owners to obtain energy on short notice under some operational and capacity constraints.

The value of a real asset is computed as the stream of profits that can be obtained from this asset through arbitrage in a liquid spot market. While the recent literature has developed increasingly sophisticated methods to model the spot price process¹ and to incorporate operational constraints (*e.g.* lead times, maximum injection or withdrawal rates and capacity constraints), it never questions two basic premises: all the relevant market information is assumed to be included in the spot price, and all the players are assumed to take this price as given. However, these assumptions are very strong, and they are likely to be violated when operators have market power, which is the case in a number of commodity markets. Our paper questions the validity of the conventional real asset valuation methods when both the spot market and the downstream market are imperfectly competitive.

First consider competition in the spot market. The assumption that traders do not take the impact of their own transactions on the market price into account can be questioned in industries where few traders make large transactions. In effect, market liquidity is an issue in a number of commodity spot markets, especially in the market for natural gas.² Many energy markets are dominated by large suppliers, and most financial traders in spot markets

¹The stochastic process governing the commodity price plays a crucial role in the pricing of related products. Models of commodity spot prices commonly use mean-reverting processes (Gibson and Schwartz, 1990; Schwartz, 1997). Models dealing with energy commodities tend to incorporate price seasonality (Manoliu and Tompaidis, 1998) and occasional price spikes (Deng, 2000).

²A market is said to be liquid when trades of any size can be transacted at any moment without causing a significant movement in price. Industry players characterise market liquidity using several indicators such as the number of players active in the market, the total volume traded, the number of trades, the churn ratio (ratio of traded volume to volume delivered physically), or the bid-ask spread. The UK spot market is the most liquid natural gas market in Europe, with roughly 70 players and a high churn ratio. Conversely, the total spot trade in the most active hubs in continental Europe (Zeebrugge in Belgium, TTF in the Netherlands) is roughly a third of that on the UK hub, while gas demand in this region is much larger (see the ECORYS report by Rademaekers, Slingenberg and Morsy, 2008, based on Heren data).

are large trading companies or divisions of major banks.³ It is reasonable to assume that these traders are aware that their transactions affect the spot price: for instance, they will avoid flooding the market if they anticipate that the resulting price decrease will lower their profits. Martinez-de-Albeniz and Vendrell Simon (2008) show that a trader who takes into account the price impact of his transactions into account can refrain from arbitrage in some cases where the price spread exceeds the transaction costs, and prefers to sell less, but at a better price. Felix, Woll and Weber (2009) specifically consider the impact of limited liquidity on gas storage valuation; to model the impact of traded volumes on the spot price, they introduce an illiquidity parameter that determines the bid-ask spread, but the lack of liquidity is not explicitly related to strategic interactions between firms with market power.

In the case of commodities, the spot market only exists because there is a downstream market and a final demand for the commodity. Our model features two types of players: pure traders, who use their physical assets⁴ for arbitrage transactions on the spot market, and suppliers, whose core business consists in purchasing a commodity and reselling it to downstream customers (of course, they have the ability to make arbitrage transactions as well). The model considers the issue of real asset valuation under imperfect competition and is applied to the valuation of natural gas storage capacities.⁵ Is the value of a real asset identical for the two types of players? In other words, is the trading value, based on the sole spot price, the right value for a firm with supply activities? In principle, at least in a competitive context with liquid markets, the spot price process should simply reflect the fundamentals of supply and demand; therefore it should include all the information that is relevant to any type of player. Secomandi (2009) proves that under perfect competition, the value of pipeline capacity is the same for a pure trader and a shipper. However, if there is market power in the downstream market, selling on spot or downstream ceases to be indifferent: a firm that has the ability to sell downstream (*e.g.*, because it has the necessary authorisations,

³On the APX Gas UK exchange, the five largest traders accounted for around half of traded volume in 2008 (Ofgem, 2009).

⁴Financial traders and the buying and selling of forward contracts or futures could also be introduced without changing the results, as long as the no-uncertainty assumption is maintained and there is free entry in the financial market. The number of physical traders, however, is bounded due to the scarcity of storage.

⁵The model could be extended to the valuation of other real conversion assets: while storage capacity can be interpreted as converting natural gas today into natural gas at a later date, “pipeline capacity can be interpreted as an asset that can convert natural gas at one location into natural gas at a different location” (Secomandi, 2009). Finally, the analysis could be applied to real assets that convert one commodity into another, *e.g.*, converting coal, fuel or natural gas into electricity.

access to the network, or a large customer base) could make more profit than a pure trader with the same real asset.

To our knowledge, the only paper that compares the value of a real asset for different types of agents in an oligopolistic setting is Sioshansi (2009). Building on the analysis developed in Sioshansi et al. (2009), which describes the impact of large-scale electricity storage on electricity prices, and thus on generators' profits and consumer surplus, Sioshansi (2009) examines the incentives for three different agent types (producers, merchant storage operators and consumers) to use storage. Under perfect competition these incentives are identical, but in an oligopolistic setting they are lowest for producers and highest for consumers. In some respects, his model is similar to ours: all storage operators are aware that the use of storage will reduce its arbitrage value, and the model compares the use of storage by operators playing different roles in the market. In Sioshansi's model, however, demand is completely inelastic, and consumers pay the real-time spot price (there are no intermediaries between producers and consumers, which is common in the market for electricity but much less so for natural gas). Conversely, demand in our model is only inelastic in the short run because consumers buy from suppliers under two-period contracts that guarantee them a fixed price over the two periods. In the longer run, demand becomes elastic because suppliers compete for contracts with downstream customers, who choose the lowest price. Another significant difference is that our model allows for the simultaneous use of storage by traders and suppliers, and more importantly, it takes the initial allocation of storage capacities into account. As we will prove, the results are drastically changed by whether this initial allocation is symmetric or characterised by a dominant operator.

The remainder of this paper is organised as follows. A stylised model of the natural gas market with no uncertainty is proposed in section 2 with two types of strategic players: pure traders and suppliers with downstream customers. Section 3 compares three methods for the pricing of storage capacity. First, myopic valuation corresponds to the usual technique with a price-taking assumption. The second method computes the actual trading value of the asset, taking the impact of transactions on the spot price into account. The third method computes the value of additional storage capacity for a supplier who uses it to supply his downstream customers. The analysis sheds light on the biases generated by traditional pricing techniques: while ignoring the price response to one's transactions leads to an overestimation of the asset's value, ignoring downstream profit opportunities leads to an underestimation. Globally, the value obtained under price-taking assumptions proves to be downward biased, except for dominant suppliers with large initial capacities: in an imperfectly competitive market, traditional methods tend

to induce under-investment. Finally, section 4 analyses a situation where suppliers active in different downstream markets source their gas from the same spot market. The value of storage for a supplier proves to be affected by the demand profile of other suppliers, even though they are not his competitors. Again, traditional methods tend to underestimate the real value of storage, except in the particular case where a supplier's demand is flat and the demand of other suppliers is seasonal.

2 The model

The model considers the valuation of seasonal storage capacities under imperfect competition.⁶ To enhance the clarity of the analysis, we do not consider uncertainty (in the case of seasonal storage, demand for the next season is not precisely known in advance, but it can be reasonably anticipated). The model is divided into two periods, a low-demand period, followed by a high-demand period, which can be interpreted as a summer season followed by a winter season.⁷ The discount rate between the periods is r . For any variable y relating to the first period, y' relates to the second period.

2.1 Assumptions

Producers sell gas in a spot market⁸ to suppliers, who resell it in a downstream market. Pure traders can also buy or sell on spot, but they have no access to the downstream market.⁹

⁶Storage facilities such as depleted fields or aquifers are mainly used for seasonal storage. These specific facilities are ill-suited for short-term arbitrage because of their low withdrawal rates. This is why we rule out arbitrage operations that take place within a single season.

⁷Since natural gas is largely used for heating, gas consumption is strongly influenced by weather and subject to a significant seasonal swing. In Northwestern Europe, approximately two-thirds of the gas is consumed during the winter (October–March).

⁸Natural gas trading relies on three main channels: bilateral contracts, exchanges and OTC markets. An exchange is a marketplace where standardised products (commodities, derivatives or other financial instruments) are traded. Exchanges usually provide a day-ahead market, also called a spot market, and allow for trading in future (standardised) contracts. Over-the-counter (OTC) trades account for the majority of traded gas volumes, especially for forward contracts. OTC trades are neither standardised nor anonymous, and they are usually facilitated by brokers. In this paper, the 'spot market' relates more generally to the market where all short-term trades take place.

⁹Approximately one-third of the actors in Zeebrugge, the largest European gas hub, are physical or financial traders with no downstream customers.

To simplify, there is a single, non-strategic producer with a production cost function

$$C(Q) = \frac{1}{2}Q^2 + bQ. \quad (1)$$

He produces q in the first period and q' in the second period. The spot price is p (p' in the second period). The inverse spot supply function can easily be computed: $p = b + q$ and $p' = b + q'$ in the first and the second periods, respectively.

The other firms active in the spot market are strategic players: m traders (indexed by i , $i = i_1, \dots, i_m$) and n suppliers (indexed by j , $j = j_1, \dots, j_n$) are competing in quantities. Trader i and supplier j are spot buyers if their spot positions s_i , s_j (s'_i , s'_j in the second period) are positive numbers. Suppliers sell gas to final consumers in the downstream market.

Demand for natural gas is not completely inelastic, but in practice consumer prices tend to be fixed for some period of time so that they do not respond to demand variations in the short term. In the longer term, however, contract prices can be modified. We assume that suppliers compete in quantities for two-period contracts with final consumers. Consumer demand is seasonal: a consumer signing a contract for quantity z at a price p_z per unit will consume a fraction $(1 - x)$ of this volume in the first period, and a fraction x in the second period, where $\frac{1}{2} \leq x \leq 1$. A high value of x denotes a strongly seasonal demand, while x close to $\frac{1}{2}$ denotes a flat demand profile. The demand for gas by final consumers is elastic, it is modelled as a linear function: $z = d - p_z$.

Suppliers and traders have access to limited storage capacities. The use of storage between the two periods costs c per unit injected. In the first period, trader i ($i = i_1, \dots, i_m$) injects $w_i \leq K_i$ and supplier j ($j = j_1, \dots, j_n$) injects $w_j \leq K_j$ into storage. By assumption, all inventories have to be emptied by the end of the second period:¹⁰ therefore, in the second period, these quantities are withdrawn and sold either on spot, or in the downstream market.

The timing can be summarised as follows.

¹⁰Clearly, this is a strong assumption because it means that injecting w_j amounts to a commitment to sell this quantity in the next period. However, in a seasonal setting, keeping volumes in stock from one year to another is uneconomical and is rarely practiced. Of course, stating that at equilibrium there should be no unsold inventory at the end of the gas year is not equivalent to introducing such a constraint, but in practice, the contracts of many storage operators (*e.g.*, E-ON Ruhrgas, RWE Energy, NAM, Dong Storage, and Edison Stoccaggio) do stipulate that no volume should be left in stock at the end of the gas year, as detailed in their respective websites. Stoccaggio) do stipulate that no volumes be left in stock at the end of the gas year, as detailed in their respective websites.

- First period

The producer sells q at price p in the spot market. Trader i buys w_i and injects it into inventory. Suppliers compete for contracts with downstream customers. Supplier j commits to sell z_j at price p_z over the two periods; he buys s_j on spot, sells $(1 - x)z_j$ to his customers, and saves the remaining quantity w_j as inventory for the next period.

- Second period

The producer sells q' at price p' in the spot market. Trader i withdraws w_i from his stocks and sells it on spot. Supplier j has to sell xz_j to his downstream customers: he withdraws w_j from his stocks and adjusts his spot position, so that $s'_j = xz_j - w_j$ (positive if he is a spot buyer).

To simplify the notation, the following convention is used: for any variable y , $y_{-i} = \sum_{\substack{k \in \{i_1, \dots, i_m\} \\ k \neq i}} y_k$ and $y_{-j} = \sum_{\substack{k \in \{j_1, \dots, j_n\} \\ k \neq j}} y_k$. Indices shall be dropped whenever the resulting notation is not ambiguous, *e.g.*, Σw_i represents $\sum_i w_i$. The game is solved backwards.

2.2 Second period

The second-period spot price results from the equilibrium between demand and supply:

$$p' = b - \Sigma w_i - \Sigma w_j + x \Sigma z_j. \quad (2)$$

There is no strategic choice to make. The traders simply sell the quantities stored in the previous period, and the suppliers adjust their spot market position depending on their inventories and downstream sales. Note that some suppliers—but not all of them—can be spot sellers in the second period if they have built up large inventories, exceeding the volume needed to supply their customers.

All stocks have the same effect of decreasing the second-period spot price either by increasing spot supply in the case of traders or suppliers who are spot sellers, or by decreasing spot demand in the case of suppliers who are spot buyers.

2.3 First period

In the first period, competition takes place simultaneously in the downstream market and in the spot market. All traders and suppliers are necessarily spot buyers. Trader i injects into storage a volume that cannot exceed his maximum capacity ($w_i \leq K_i$). Supplier j , who commits to sell z_j to his

customers over the two periods, simultaneously buys on spot s_j , sells $(1-x)z_j$ downstream, and injects the remaining quantity $w_j = s_j - (1-x)z_j$ into storage ($w_j \leq K_j$). The first-period spot market equilibrium is

$$p = b + \sum_i w_i + \sum_j w_j + (1-x) \sum_j z_j. \quad (3)$$

We introduce the following definitions.¹¹ Let

$$\alpha \equiv (1+r) \frac{\partial}{\partial z_j} \left(\frac{p'}{1+r} - p - c \right), \quad (4)$$

$$\beta \equiv -(1+r) \frac{\partial}{\partial z_j} \left(p_z - (1-x)p - x \frac{p'}{1+r} \right). \quad (5)$$

α is the marginal increase in arbitrage profits (multiplied by $(1+r)$) when a supplier's downstream sales increase by one unit, which amplifies the price spread. Symmetrically, α is also equal to the marginal increase in supply profits (multiplied by $(1+r)$) when inventories increase by one unit, which smoothes spot prices, thereby lowering suppliers' purchasing costs:

$$\alpha = (1+r) \frac{\partial}{\partial w_j} \left(p_z - (1-x)p - x \frac{p'}{1+r} \right). \quad (6)$$

β is the marginal decrease in supply profits (in absolute value, multiplied by $(1+r)$) when a supplier's downstream sales increase by one unit: when the demand profile is not flat, more sales mean increasing the purchasing price even more in the period where it is already higher. Computing the values of α and β , we see that α is large when demand in the second period is high relative to the first period, and β is large when the swing (difference in demand) between the two periods is large, with a higher demand in either period:

$$\alpha = x - (1+r)(1-x), \quad (7)$$

$$\beta = 2(1+r)(1-x+x^2) - rx^2. \quad (8)$$

β is always positive, and $\alpha > 0$ if $x > \frac{1}{2} + \frac{r(1-x)}{2}$. In the rest of the analysis, we assume that $\alpha > 0$.

¹¹Note that α and β are well-defined because in both equations, the right-hand side is the same for all j .

2.3.1 Downstream sales

A supplier's activity can be decomposed into trading on the one hand, and supply to downstream customers on the other:

$$\Pi_j = \left(\frac{p'}{1+r} - p - c \right) w_j + \left(p_z - (1-x)p - x \frac{p'}{1+r} \right) z_j. \quad (9)$$

Competing in quantities with the other suppliers, supplier j chooses his total downstream sales z_j to maximise his intertemporal profit, taking his rivals' sales and all inventories as given. The marginal impact of additional downstream sales on his profit is

$$\frac{\partial \Pi_j}{\partial z_j} = \left(p_z - (1-x)p - x \frac{p'}{1+r} \right) + \frac{1}{1+r} (\alpha w_j - \beta z_j). \quad (10)$$

When combining the first-order conditions of all suppliers, the sales of supplier j prove to increase with the inventories of traders and own inventories only

$$z_j = \frac{1}{(n+1)\beta} ((1+r)d - (1+r(1-x))b) + \frac{\alpha}{(n+1)\beta} \Sigma w_i + \frac{\alpha}{\beta} w_j. \quad (11)$$

All inventories have a positive direct effect on the sales of supplier j because they reduce the spot price spread, thereby reducing his sourcing costs. However, rival suppliers holding inventories tend to compete more aggressively, which counters this positive effect, so that the net effect of their stocks is zero (they can only have an indirect effect through the impact on unconstrained traders' stocks). In contrast, own inventories have an additional positive effect: these units are purchased at a lower price. Therefore, holding more inventories allows a supplier to increase his downstream sales.

Total sales in the downstream market can be expressed as

$$\Sigma z_j = \frac{1}{\beta} \frac{n}{n+1} ((1+r)d - (1+r-rx)b) + \frac{\alpha}{\beta} \frac{n}{n+1} \Sigma w_i + \frac{\alpha}{\beta} \Sigma w_j. \quad (12)$$

These sales increase more with the stocks of suppliers than with the stocks of traders. This is because each supplier's sales increase more with his own inventories than with traders' stocks, while they are not directly affected by the stocks of rival suppliers.

2.3.2 Inventory choice by a trader

Trader i chooses his stocks w_i ($0 \leq w_i \leq K_i$), taking into account the impact of his transactions on the spot prices: one additional unit of inventories causes the first-period spot price to increase and the second-period spot

price to decrease (arbitrage transactions reduce the price spread). He solves $\max_{w_i \leq K_i} \Pi_i$, where

$$\Pi_i = \left(\frac{p'}{1+r} - p - c \right) w_i. \quad (13)$$

The marginal effect of one additional unit of inventories, if the trader is not capacity-constrained, is

$$\frac{\partial \Pi_i}{\partial w_i} = \left(\frac{p'}{1+r} - p - c \right) - \left(\frac{\partial p}{\partial w_i} + \frac{1}{1+r} \frac{\partial p'}{\partial w_i} \right) w_i \quad (14)$$

$$= \left(\frac{p'}{1+r} - p - c \right) - \frac{2+r}{1+r} w_i. \quad (15)$$

The best response of trader i to other players' stocks and to suppliers' sales is

$$w_i = \frac{1}{2(2+r)} (\alpha \Sigma z_j - rb - (1+r)c) - \frac{1}{2} (\Sigma w_j + w_{-i}) \quad (16)$$

if the right-hand side is positive and lower than K_i , else $w_i = 0$ or $w_i = K_i$. The equilibrium profit of a trader only depends on the amount w of his inventories; it shall be denoted as $T(w)$.

2.3.3 Inventory choice by a supplier

Supplier j chooses his stock level to maximise his intertemporal profit given by (9), under the constraints $0 \leq w_j \leq K_j$. Note that, given the expressions for p and p' , the derivative of $\left(\frac{p'}{1+r} - p - c \right)$ with respect to w_j is equal to its derivative with respect to w_i , so that

$$\frac{\partial}{\partial w_j} \left[\left(\frac{p'}{1+r} - p - c \right) w_j \right] = T'(w_j). \quad (17)$$

Accordingly, the impact of one additional unit of inventories on the profit of a supplier can be expressed as

$$\frac{\partial \Pi_j}{\partial w_j} = T'(w_j) + \frac{\alpha}{1+r} z_j. \quad (18)$$

- **The first term** is equal to the effect of one additional unit of inventory on the profit of a pure trader holding w_j in stock. This term combines two elements: the substitution effect of buying and storing one unit more in the first period instead of buying it in the second period; and the impact of these transactions on the spot prices, and thus indirectly on the costs of purchasing and the revenues from selling the entire volume w_j .

- **The second term** is the global decrease in purchasing costs due to the price-smoothing effect of inventories, which makes downstream sales more profitable.

For a supplier, storage is not only an arbitrage tool, it also increases purchases in the low-demand period and lowers them in the high-demand period, which globally reduces purchasing costs, and therefore yields additional profits. This allows us to state the following Lemma.

Lemma 1. *Suppliers with non-binding storage capacities always carry more inventories than traders.*

Proof. Let w_j be the equilibrium stock of supplier j , with $w_j < K_j$: $\partial \Pi_j / \partial w_j \leq 0$. Therefore, from (18), $T'(w_j) \leq -\frac{\alpha}{1+r} z_j$, which is negative. For any trader i with positive inventories, $T'(w_i) \geq 0$. Therefore, $T'(w_j) \leq T'(w_i)$, and because the function T' is strictly decreasing, $w_j \geq w_i$. \square

Analysing equations (18) and (15) leads us to a second result.

Lemma 2. *If no supplier is constrained by his storage capacity, then there can be no traders.*

Proof. See Appendix. \square

The best response of supplier j to the stocks of other suppliers and traders is

$$w_j = \frac{1}{2(2+r)} (\alpha(z_j + 2z_{-j}) - rb - (1+r)c) - \frac{1}{2}(\Sigma w_i + w_{-j}) \quad (19)$$

if the right hand-side is positive and lower than K_j , else $w_j = 0$ or $w_j = K_j$.

We introduce the following notations:

$$D = (1+r)d - (1+r-rx)b, \quad (20)$$

$$C = rb + (1+r)c. \quad (21)$$

If no supplier is constrained, there are no traders and suppliers' stocks are

$$\Sigma w_j = \frac{n}{n+1} \frac{\alpha D - \beta C}{(1+r)(3+r)}. \quad (22)$$

In this case, the spot price differential is:

$$\frac{p'}{1+r} - p - c = -\frac{rb + (1+r)c}{(n+1)(1+r)}. \quad (23)$$

When the downstream market is perfectly competitive (n tends to infinity), the price spread is completely smoothed by storage. When it is imperfectly competitive, an individual supplier does not take into account the fact that increasing his own stocks reduces the value of storage for the other suppliers, so that at equilibrium, suppliers carry “too much” inventory and the price spread is negative.

If at least one supplier is constrained, the equilibrium in the general case where some suppliers and some traders can be capacity-constrained is detailed in the Appendix.

The social welfare, *i.e.*, the sum of the surplus of consumers and the profits of the traders, the suppliers and the producer, can be expressed as

$$\begin{aligned}
SW = & p_z \Sigma z_j + \frac{1}{2} (\Sigma z_j)^2 - c \Sigma w - (b + \frac{1}{2} ((1-x) \Sigma z_j + \Sigma w)) ((1-x) \Sigma z_j + \Sigma w) \\
& - \frac{1}{1+r} (b + \frac{1}{2} (x \Sigma z_j - \Sigma w)) (x \Sigma z_j - \Sigma w).
\end{aligned} \tag{24}$$

How should storage capacities be allocated to maximise social welfare? Obviously, if some operators do not use their entire storage capacity, it is preferable to reallocate them to other operators that lack capacity. What if all operators are constrained? The expression in (24) increases with Σw and with Σz_j . From (95), Σw increases more with Σw_j than with Σw_i when there are some unconstrained traders, and otherwise the effect is identical. Downstream sales increase more with Σw_j than with Σw_i (see (12)). As a consequence, when allocating scarce storage capacities, it is always better to give priority to capacity-constrained suppliers, because this will lead to a larger increase in their downstream sales, which benefits consumers. Conversely, when no supplier is constrained, as stated by Lemma 1, there is no need to allocate capacities to traders because they would not use them.

Proposition 1. *Giving storage capacities to pure traders is never welfare-improving. If some suppliers are capacity-constrained, it would be preferable to reallocate these capacities to them; if no supplier needs additional capacity, then traders cannot make any profit in the market.*

Therefore, when storage is scarce, clear priority should be given to operators with downstream customers. Some countries already apply such a policy. In France, available storage capacities are allocated to suppliers according to storage rights based on their current customer portfolio¹²; if storage capacities are scarce, operators that supply gas to domestic customers or customers

¹²Article 5, Loi n° 2003-8 du 3 janvier 2003 relative aux marchés du gaz et de l’électricité et au service public de l’énergie.

under non-interruptible contracts have a priority over, *e.g.*, pure traders.¹³ Note, however, that under our assumptions, the distribution of capacities between constrained suppliers plays no role: both total inventories and total downstream sales depend on the number of constrained operators and on total constraining capacities, but not on the way that the capacity is allocated among the operators. As long as no storage capacities remain idle, a reallocation of capacities among suppliers has no impact on social welfare. This is not necessarily true in the case of suppliers with different demand profiles, as will be discussed in section 4.

3 Storage valuation with market power

This section is devoted to investments in new storage capacity. The analysis focuses on the case where all suppliers and traders are capacity-constrained. If this were not the case, it could be profitable for an operator with excess capacity to lend it to a capacity-constrained operator, unless withholding available capacity proved to be even more profitable. Since such foreclosure strategies are not the focus of this paper, we shall assume that all operators are capacity-constrained: $w_i = K_i$ for all i and $w_j = K_j$ for all j . This section compares three methods for the valuation of storage capacity:

1. the myopic valuation, $\tilde{V} \equiv \frac{p'}{1+r} - p - c$,
2. the trading valuation $V_i \equiv \frac{\partial \Pi_i}{\partial K_i}$,
3. the supplier valuation $V_j \equiv \frac{\partial \Pi_j}{\partial K_j}$.

We analyse the bias generated by the use of the “traditional” methods that simply compute the arbitrage profits of a price-taking trader when the storage facility is to be used by a trader with market power, or by a supplier. The myopic valuation is identical for all operators because it is solely based on the spot price spread and does not take the specific characteristics of each operator into account. This value can be easily computed using the expressions for the spot prices in (2) and (3), and total downstream sales are given by (12):

$$\tilde{V} = \frac{n\alpha D - (n+1)\beta C - \alpha^2 \Sigma K_i}{(1+r)(n+1)\beta} - \frac{3+r}{\beta}(\Sigma K_i + \Sigma K_j). \quad (25)$$

¹³Article 3, Décret n° 2006-1034 du 21 août 2006 relatif à l'accès aux stockages souterrains de gaz naturel.

3.1 Use of traditional techniques by a trader

The value of one additional unit of capacity for a constrained trader i is easily obtained by reformulating equation (14):

$$V_i \equiv \frac{\partial \Pi_i}{\partial K_i} = \left(\frac{p'}{1+r} - p - c \right) - \left(\frac{\partial p}{\partial K_i} + \frac{1}{1+r} \frac{-\partial p'}{\partial K_i} \right) K_i. \quad (26)$$

Note, however, that the derivative of a variable (such as p or p') with respect to storage capacity K_i is not equal to its derivative with respect to inventories w_i : when a trader chooses w_i , he takes all other inventories (as well as suppliers' sales) as given, whereas the choice of K_i is made anticipating its impact on all stocks and sales.

The bias induced by the use of the myopic valuation in the case of a trader with market power is

$$\tilde{V} - V_i = \left(\frac{\partial p}{\partial K_i} + \frac{1}{1+r} \frac{-\partial p'}{\partial K_i} \right) K_i. \quad (27)$$

The effect of a marginal increase in the capacity of trader i on the spot prices can be expressed as

$$\frac{\partial p}{\partial K_i} = 1 + \frac{n}{n+1} \frac{(1-x)\alpha}{\beta}, \quad (28)$$

$$\frac{\partial p'}{\partial K_i} = -1 + \frac{n}{n+1} \frac{x\alpha}{\beta}. \quad (29)$$

Note that $\partial p / \partial K_i > 0$ and $\partial p' / \partial K_i < 0$: the trader's first-period purchases push the spot price upwards, while his second-period sales push it downwards. As a result, the price spread, and therefore the trader's profit, is lower than if the prices were unaffected by his transactions: $\tilde{V} - V_i$ is necessarily positive. Strikingly, the number of traders m has no impact on the bias, indicating that the degree of competition in the spot market does not matter. Only the size of the trader's initial capacity determines whether his transactions will have a significant effect on spot prices. A small trader (*i.e.* with a small initial capacity) can reasonably behave as if he were a price taker.

What about the impact of imperfect competition in the downstream market? A higher K_i means a lower price spread, and thus lower overall purchasing costs for suppliers; in return, all suppliers increase their downstream sales, which reinforces spot demand especially in the second period, thereby limiting the decrease in the price spread. This countervailing effect becomes weaker when the downstream market moves away from perfect competition,

because a decrease in purchasing costs will not lead suppliers to significantly increase their sales. Accordingly, the bias is larger when the number of suppliers is small:

$$\tilde{V} - V_i = \left(\frac{2+r}{1+r} - \frac{n}{n+1} \frac{\alpha^2}{(1+r)\beta} \right) K_i. \quad (30)$$

The results are summarised in the following Proposition.

Proposition 2. *A trader with market power who ignores the impact of his transactions on spot prices always overestimates the value of additional storage capacity. This bias is reinforced by imperfect competition in the downstream market.*

Finally, the bias is proportional to the trader's initial capacity: a large trader will make a larger error.

3.2 Use of traditional techniques by a supplier

Without loss of generality, consider the case of supplier j_1 . His profit is the sum of his trading profit and his supply profit:

$$\Pi_{j_1} = \left(\frac{p'}{1+r} - p - c \right) K_{j_1} + \left(p_z - (1-x)p - x \frac{p'}{1+r} \right) z_{j_1}. \quad (31)$$

The value of additional storage capacities for him is

$$V_{j_1} \equiv \frac{\partial \Pi_{j_1}}{\partial K_{j_1}} = \frac{\alpha D - \beta C}{(1+r)\beta} - \frac{3+r}{\beta} (\Sigma K_i + \Sigma K_j + K_{j_1}). \quad (32)$$

We will now compare this value with the myopic valuation. Consider the second term in equation (31). Downstream sales z_{j_1} are affected by an increase in K_{j_1} , but the profit per unit supplied to downstream customers is not (if K_{j_1} becomes larger, z_{j_1} increases, and the resulting decrease in p_z is exactly compensated for by the increase in the cost of spot purchases):

$$p_z - (1-x)p - x \frac{p'}{1+r} = \frac{D + \alpha \Sigma K_i}{(n+1)(1+r)}. \quad (33)$$

As a result, the value of one additional unit of capacity for supplier j_1 can be expressed as

$$V_{j_1} = \left(\frac{p'}{1+r} - p - c \right) - B1_{j_1} - B2_{j_1} \quad (34)$$

where

$$B1_{j_1} = \left(\frac{\partial p}{\partial K_{j_1}} - \frac{1}{1+r} \frac{\partial p'}{\partial K_{j_1}} \right) K_{j_1}, \quad (35)$$

$$B2_{j_1} = - \left(p_z - (1-x)p - x \frac{p'}{1+r} \right) \frac{\partial z_{j_1}}{\partial K_{j_1} j}. \quad (36)$$

The error made by a supplier with market power who uses the myopic value \tilde{V} , instead of the supplier value V_{j_1} that takes into account his profits on the downstream market is

$$B_{j_1} \equiv \tilde{V} - V_{j_1} = B1_{j_1} + B2_{j_1}. \quad (37)$$

3.2.1 First bias: volume effect

The first bias $B1_{j_1}$ is due to the fact that the use of additional storage capacities by a supplier will reduce the price spread. The intuition here is the same as in the case of a pure trader, but the suppliers' stocks have a different impact on spot prices. Indeed, the stocks of suppliers have a larger upward impact on the spot price than the stocks of traders in the first period, but a smaller downward impact in the second period: since suppliers' stocks stimulate downstream sales more than traders' stocks do, they push total spot purchases upwards. Globally, the impact on the price spread is smaller when stocks are held by suppliers:

$$B1_{j_1} = \frac{3+r}{\beta} K_{j_1}. \quad (38)$$

3.2.2 Second bias: downstream market power effect

The second bias is due to the positive effect of additional storage capacities on the downstream sales of supplier j_1 . Since holding inventories allows him to buy more in the first period and less in the second period, where the spot price is higher, a higher K_{j_1} means lower sourcing costs, which leads him to compete more aggressively for downstream customers. This bias is clearly negative:

$$B2_{j_1} = - \frac{\alpha}{\beta} \frac{D + \alpha \Sigma K_i}{(n+1)(1+r)}. \quad (39)$$

3.2.3 Global bias

The global bias is $B_{j_1} \equiv B1_{j_1} + B2_{j_1}$:

$$B_{j_1} = \frac{3+r}{\beta} K_{j_1} - \frac{\alpha}{\beta} \frac{D + \alpha \Sigma K_i}{(n+1)(1+r)}. \quad (40)$$

$B1_{j_1}$ is proportional to the supplier's initial storage capacity, since arbitrage profits on all units in stock are affected by the reduction in the price spread. Conversely, $B2_{j_1}$ does not depend on the initial capacity of supplier j_1 , but it is larger in absolute terms when the downstream market is concentrated (small n). Accordingly, the sign of the global bias depends both on the degree of competition in the downstream market and on the initial allocation of storage capacities:

$$B < 0 \Leftrightarrow (n+1)K_{j_1} < \frac{\alpha D + \alpha^2 \Sigma K_i}{(1+r)(3+r)}. \quad (41)$$

The bias is more likely to be negative when the downstream market is concentrated and the initial capacity of supplier j_1 is small. Does this mean that j_1 will invest less than what is optimal for him?

By assumption, j_1 only considers investing if the myopic valuation is positive, which means (see (25)) that

$$\Sigma K_j < \frac{n\alpha D - (n+1)\beta C - \alpha^2 \Sigma K_i}{(n+1)(1+r)(3+r)} - \Sigma K_i. \quad (42)$$

If this is not the case, he will not invest; therefore his investment will be slightly lower than the optimum. Now suppose that inequality (42) is satisfied. If the capacity of supplier j_1 is equal to or lower than the average capacity of suppliers, this inequality implies that

$$nK_{j_1} < \frac{n\alpha D - (n+1)\beta C - \alpha^2 \Sigma K_i}{(n+1)(1+r)(3+r)} - \Sigma K_i, \quad (43)$$

which in turn implies that the global bias is negative (inequality (41)): supplier j_1 underestimates the value of additional investments. Finally, we can state the following Proposition.

Proposition 3. *A supplier with market power who uses the myopic valuation method, thereby ignoring both the impact of his transactions on the spot price and the downstream profits to be expected from larger stocks underestimates the value of additional storage capacity, as long as his initial capacity is not higher than the average capacity of suppliers.*

In fact, if the initial capacity allocation is (at least roughly) symmetric, the bias is negative for all suppliers. In this case, traditional methods based on arbitrage pricing systematically underestimate the profits from new storage capacity and lead to under-investment. This is all the more true as the downstream market is concentrated (small n).

The only situation where the myopic valuation can lead to over-investment with respect to the profit-maximising level is when $\tilde{V} > 0$ and $B_{j_1} > 0$, which holds if and only if

$$\Sigma K_j < \frac{n\alpha D - (n+1)\beta C - \alpha^2 \Sigma K_i}{(n+1)(1+r)(3+r)} - \Sigma K_i < \frac{n\alpha D + n\alpha^2 \Sigma K_i}{(n+1)(1+r)(3+r)} < nK_{j_1}. \quad (44)$$

This is only possible when the initial capacity allocation is highly asymmetric, with most available capacities allocated to j_1 . When one dominant supplier owns a large proportion of the available capacity, the use of traditional valuation methods can lead him to overestimate the value of additional storage capacity. However, the other suppliers will underestimate it.

Finally, another side-effect of the use of the myopic valuation is to inhibit the growth of small suppliers in the downstream market. In effect, if all suppliers would use the actual valuation, suppliers with less initial capacity would be more induced to invest, which would progressively re-equilibrate capacity allocation. Instead, the use of the same myopic valuation \tilde{V} by all suppliers irrespective of their initial capacities tends to maintain the initial storage capacity positions of the suppliers, and hence, to freeze their downstream market shares.

4 Storage valuation and demand characteristics

Suppliers buying on the same spot market can be active in different downstream markets. Gas markets in Europe are organised on a regional basis around a small number of hubs, and the suppliers who meet there are not necessarily competing in the same geographical markets.¹⁴ In addition, even in a single country, suppliers can serve different customer segments: incumbents tend to serve most residential customers, while new entrants specialise in supply to the business or manufacturing sectors. These customer segments can have very different demand profiles: typically, residential demand exhibits a strong seasonal swing as more gas is used in the winter for heating, whereas industrial demand is rather flat throughout the year.

¹⁴A gas hub is the point of entry into a natural gas transmission network. Hubs draw supply from a variety of sources and enable suppliers to market gas to their customers. A gas hub can be a physical location, usually a pipeline network node, or a virtual trading point (like the National Balancing Point (NBP) in Great Britain) where gas products are financially traded but not physically delivered. For a description of European gas hubs, see the Ecorys report (2008).

In this section, we prove that when a supplier interacts in the spot market with firms active in other downstream markets, his valuation of storage is affected both by his own demand profile and by the demand profile of the other operators.

Consider two suppliers, A and B , each active in a different downstream market. They face demands characterised by

$$p_A = d - z_A, \quad (45)$$

$$p_B = d - z_B, \quad (46)$$

where p_j and z_j (for $j = A, B$) are the price and the total quantity sold on market j , *i.e.* the market where supplier j is active. As in the previous section, supplier j commits to sell to his customers at price p_j a total quantity z_j , of which a proportion $1 - x_j$ is to be sold in a first period and a proportion x_j in a second period. We assume that d is the same in both markets, to focus on the impact of seasonality (x_A and x_B can differ).

To simplify, we suppose that suppliers A and B are the only operators active in the spot market. As in the previous section, a price-taking producer whose production cost function is given by (1) is assumed to sell gas on the spot market. The spot prices in the first and second periods are, respectively,

$$p = b + w_A + w_B + (1 - x_A)z_A + (1 - x_B)z_B, \quad (47)$$

$$p' = b - w_A - w_B + x_A z_A + x_B z_B. \quad (48)$$

Suppliers have access to storage: supplier j can store $w_j \leq K_j$ between the two periods. To simplify, both the storage cost and the interest rate are set to zero. The timing is similar to the previous section. In the first period, suppliers simultaneously choose their spot market positions, downstream sales and inventories. In the second period, they deplete their inventories and adjust their spot market positions to obtain the volumes needed to supply their downstream customers.

As previously, we introduce the following notations: for $j = A, B$, let

$$\alpha_j \equiv \frac{\partial(p' - p)}{\partial z_j} \quad (49)$$

$$= 2x_j - 1 \quad (50)$$

denote the marginal impact of sales in the downstream market j on the spot price spread; α_j is positive if demand in market j is higher in the second period than in the first period. Let

$$\beta_j \equiv -\frac{\partial(p_j - (1 - x_j)p - x_j p')}{\partial z_j} \quad (51)$$

$$= 2(1 - x_j + x_j^2) \quad (52)$$

denote, in absolute terms, the impact of additional downstream sales in market j on the profit per unit sold in this market; β_j is large if the seasonal profile of demand in market j is strongly marked (demand can be higher in either period), because in this case an increase in z_j tends to increase the spot price especially in the period where supplier j 's spot demand is already high, which increases the average cost per unit purchased. Note that β_j is always strictly positive. Finally, let

$$\gamma_{AB} \equiv -\frac{\partial(p_A - (1 - x_A)p - x_A p')}{\partial z_B} \quad (53)$$

$$= x_A x_B + (1 - x_A)(1 - x_B) \quad (54)$$

denote, in absolute terms, the impact of additional sales by supplier B in his downstream market on the profit per unit sold by supplier A in his own downstream market; γ_{AB} is higher when the demand profile is similar in both markets (x_A and x_B are close to each other), because in this case a higher z_B tends to increase the spot price, especially in the period where A 's spot purchases are higher, which adversely affects the supply profits of A . Note that $\gamma_{AB} = \gamma_{BA}$.

4.1 Equilibrium with no capacity constraints

The profit of supplier j is

$$\Pi_j = (p_j - (1 - x_j)p - x_j p')z_j + (p' - p)w_j. \quad (55)$$

In the second period, there is no strategic choice to make, and supplier j simply buys $x_j z_j - w_j$ on spot, so as to sell $x_j z_j$ to his downstream customers. Now consider the choice of downstream sales and inventories by supplier A in the first period. He is a monopolist in his downstream market, but he interacts with the other supplier in the spot market. As in the previous section, we assume that suppliers are aware of the impact of their transactions on the spot prices. The derivatives of supplier A 's profit with respect to his own sales and inventories are

$$\frac{\partial \Pi_A}{\partial z_A} = (d - z_A - (1 - x_A)p - x_A p') + \alpha_A w_A - \beta_A z_A, \quad (56)$$

$$\frac{\partial \Pi_A}{\partial w_A} = (p' - p) + \alpha_A z_A - 2w_A. \quad (57)$$

The first-order condition with respect to z_A is

$$z_A = \frac{1}{2\beta_A} (d - b - \gamma_{AB} z_B + \alpha_A (2w_A + w_B)). \quad (58)$$

As expected, the sales of supplier A decrease when the other supplier's sales increase, because higher spot purchases by B increase the sourcing costs of supplier A . Given z_B , the sales of supplier A increase with all inventories — because all inventories reduce the price spread — but they increase more with his own inventories, which are bought at a cheaper price and carried over to the high-demand period, thereby lowering his total purchasing costs.

The first-order condition with respect to w_A is

$$w_A = \frac{1}{4}(2\alpha_A z_A + \alpha_B z_B - 2w_B). \quad (59)$$

If both $\alpha_A > 0$ and $\alpha_B > 0$, the stocks of the two suppliers are

$$w_A = \frac{\alpha_A(d-b)}{7}, \quad (60)$$

$$w_B = \frac{\alpha_B(d-b)}{7}. \quad (61)$$

The inventories smooth the spot price differential ($p' = p$), and therefore downstream sales are identical ($z_A = z_B = 2(d-b)/7$).

If only $\alpha_A > 0$ but $\alpha_B \leq 0$ (supplier B 's demand profile is opposed to that of supplier A), the equilibrium inventories and sales are

$$w_A = \frac{3}{2(9\beta_B + 4)} \left(\alpha_A \beta_B + \frac{\alpha_A + 5\alpha_B}{6} \right) (d-b), \quad (62)$$

$$w_B = 0, \quad (63)$$

$$z_A = \frac{(1 + 6\beta_B)}{2(9\beta_B + 4)} (d-b), \quad (64)$$

$$z_B = \frac{5}{9\beta_B + 4} (d-b), \quad (65)$$

if and only if

$$\alpha_A \beta_B + \frac{\alpha_A + 5\alpha_B}{6} > 0. \quad (66)$$

In this case, A holds inventories, but they are reduced due to the lower spot demand by B in the period where A 's demand is high. Otherwise, if α_A is not large enough to compensate for the negative α_B , supplier A is not induced to carry inventories at all, even though his own demand profile increases over the two periods. To summarise, A holds inventories if and only if

$$\alpha_A > 0 \text{ and} \quad (67)$$

$$\max \left(\alpha_B, \alpha_A \beta_B + \frac{\alpha_A + 5\alpha_B}{6} \right) > 0 \quad (68)$$

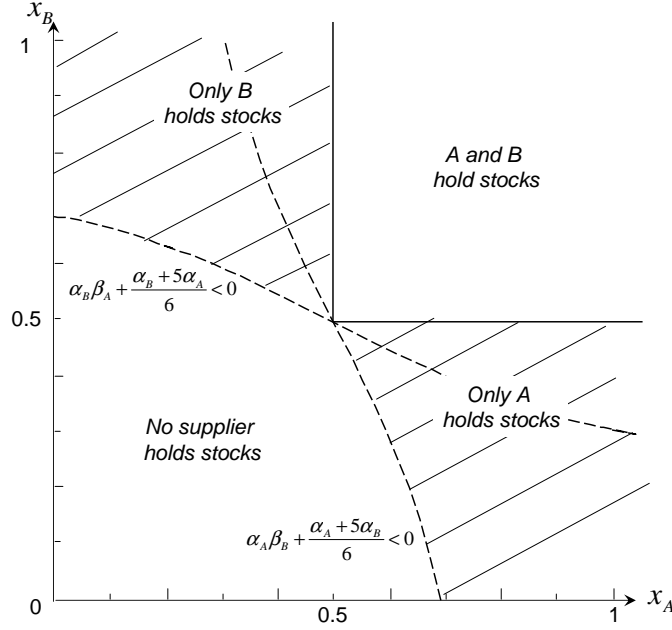


Figure 1: Storage behaviour as a function of both suppliers' demand profiles (case with no capacity constraints).

4.2 Equilibrium with capacity constraints

First assume, without loss of generality, that only supplier B is constrained: $w_B = K_B$. Combining the first-order conditions of both suppliers' programmes with respect to sales and inventories yields the optimal inventory choice of A :

$$w_A = \frac{3}{2(9\beta_B + 4)} \left(\left(\alpha_A \beta_B + \frac{\alpha_A + 5\alpha_B}{6} \right) (d - b) - \left(\frac{16}{3} + \gamma_{AB} \right) K_B \right) \quad (69)$$

if the right-hand side is lower than K_A (else $w_A = K_A$), and positive (else $w_A = 0$). Contrary to the unconstrained case, if B 's demand is much higher in the second period and B 's storage capacity is low, A will carry inventories even if his own demand is lower in the second period ($\alpha_A \leq 0$). In other words, supplier A carries inventories for supplier B , whose storage capacities are insufficient.

We shall focus on the case where both suppliers are capacity-constrained and they consider expanding their storage capacity. Given that supplier B is capacity-constrained, supplier A is constrained if and only if his capacity

does not allow him to play his best response:

$$K_A < \frac{3}{2(9\beta_B + 4)} \left(\left(\alpha_A \beta_B + \frac{\alpha_A + 5\alpha_B}{6} \right) (d - b) - \left(\frac{16}{3} + \gamma_{AB} \right) K_B \right), \quad (70)$$

and the condition for supplier B is obtained by symmetry.

Combining the first-order conditions of each supplier's programme with respect to his own sales yields

$$z_A = \frac{1}{4\beta_A\beta_B - \gamma_{AB}^2} ((2\beta_B - \gamma_{AB})(d - b) + (4\beta_B\alpha_A - \gamma_{AB}\alpha_B)K_A + 2(\beta_B\alpha_A - \alpha_B\gamma_{AB})K_B), \quad (71)$$

$$z_B = \frac{1}{4\beta_B\beta_A - \gamma_{AB}^2} ((2\beta_A - \gamma_{AB})(d - b) + (4\beta_A\alpha_B - \gamma_{AB}\alpha_A)K_B + 2(\beta_A\alpha_B - \alpha_A\gamma_{AB})K_A). \quad (72)$$

As expected, a supplier's sales increase with his own storage capacity. The effect of the other supplier's storage capacity is ambiguous. Consider the effect of K_A on z_B .

- A first, direct effect is related to the reduction of the price spread due to additional stocks: this effect is positive if $\alpha_B > 0$ ($x_B > \frac{1}{2}$).
- As can be seen from equation (58), K_A also has an indirect effect on z_B through its impact on z_A : the increase in supplier A 's downstream sales is all the larger as the cost savings from additional stocks are significant, *i.e.*, x_A is large. In turn, a larger z_A will push spot prices upwards, which will negatively affect B , all the more so as the demand profiles are correlated (that is, A 's additional demand tends to raise the spot price especially in the period where B purchases larger quantities on spot). The latter effect is proportional to γ_{AB} .
- The global effect of K_A on the sales of supplier B is proportional to $\beta_A\alpha_B - \alpha_A\gamma_{AB}$, which can be computed explicitly:

$$\beta_A\alpha_B - \alpha_A\gamma_{AB} = 3(x_B - \frac{1}{2}) - (x_A - \frac{1}{2}). \quad (73)$$

This effect is positive if the demand in market B is much higher in the second period than in the first, and/or if demand in market A is rather flat or higher in the first period. The impact of K_A on total sales can be positive or negative:

$$\frac{\partial(z_A + z_B)}{\partial K_A} = \frac{3}{4\beta_A\beta_B - \gamma_{AB}^2} \left(\alpha_A\beta_B + \frac{\alpha_A + 5\alpha_B}{6} \right). \quad (74)$$

The denominator is strictly positive, but $\alpha_A + 5\alpha_B$ can be sufficiently negative for the right-hand side to be negative. This leads us to state the following counterintuitive result.

Lemma 3. *Total sales of suppliers in the various downstream markets can decrease when a supplier expands his storage capacity, if the other supplier's demand profile is strongly "countercyclical".*

4.3 Storage valuation

4.3.1 Myopic storage valuation

A supplier who does not take the impact of his transactions on the spot prices into account will calculate the value of one additional unit of storage capacity as follows:

$$\tilde{V} \equiv p' - p \quad (75)$$

$$= -2(K_A + K_B) + \alpha_A z_A + \alpha_B z_B. \quad (76)$$

Reinjecting the equilibrium sales from (71) and (72) yields

$$\begin{aligned} \tilde{V} = & \frac{1}{2(4\beta_A\beta_B - \gamma_{AB}^2)} ((\alpha_A + \alpha_B)(\alpha_A\alpha_B + 5)(d - b) \\ & - 2(\gamma_{AB} + 6\beta_B + 8)K_A - 2(\gamma_{AB} + 6\beta_A + 8)K_B). \end{aligned} \quad (77)$$

The denominator is positive. When K_A and K_B are sufficiently small, the myopic valuation is positive whenever $\alpha_A + \alpha_B > 0$ (if the demand profiles are opposed, the inequality holds if the demand swing is larger in the market where demand is higher in the second period).

4.3.2 Actual storage valuation

When computing the additional profits from a marginal increase in storage capacity, a supplier has to take into account its consequences on the spot prices, whether they are direct or indirect (through a change in the other supplier's behaviour). Let $V_A \equiv \partial\Pi_A/\partial K_A$ denote the value of additional storage capacities for supplier A ,

$$V_A = (p' - p) + \frac{\partial(p' - p)}{\partial K_A} K_A + \frac{\partial((p_A - (1 - x_A)p - x_A p')z_A)}{\partial K_A}. \quad (78)$$

Let us analyse the difference between this valuation and the myopic valuation $\tilde{V} \equiv p' - p$. The global bias $\tilde{V} - V_A$ can be decomposed into a first bias,

related to cost savings from spot arbitrage, and a second bias, related to downstream profits:

$$\tilde{V} - V_A = -\frac{\partial(p' - p)}{\partial K_A} K_A - \frac{\partial((p_A - (1 - x_A)p - x_{AP'})z_A)}{\partial K_A}. \quad (79)$$

First, the price spread $p' - p$ is not constant with respect to K_A . As is clear from equation (76), additional storage capacities have a direct, negative impact on the price spread, and also have an indirect impact through their impact on equilibrium sales, whose sign is ambiguous according to Lemma 3. Globally, the impact of a higher K_A on the price spread is always negative, so that the first bias is positive:

$$-\frac{\partial(p' - p)}{\partial K_A} = \frac{\gamma_{AB} + 6\beta_B + 8}{4\beta_A\beta_B - \gamma_{AB}^2}.$$

Due to this volume effect, which reduces the savings actually achieved through the use of inventories, the myopic valuation tends to overstate the value of storage.

In addition, A and B are not pure traders; they also supply downstream customers, which leads to a second bias, because downstream profits are affected by a change in K_A :

$$\begin{aligned} -\frac{\partial((p_A - (1 - x_A)p - x_{AP'})z_A)}{\partial K_A} &= -(p_A - (1 - x_A)p - x_{AP'})\frac{\partial z_A}{\partial K_A} \\ &\quad - \frac{\partial(p_A - (1 - x_A)p - x_{AP'})}{\partial K_A} z_A \end{aligned} \quad (80)$$

On the one hand, a supplier's sales increase with additional storage capacities if storage is justified by his own downstream demand: from (71), $\partial z_A / \partial K_A = 4\beta_B\alpha_A - \gamma_{AB}\alpha_B$, and because $4\beta_B$ is large compared to γ_{AB} , $\partial z_A / \partial K_A$ will generally be positive when $\alpha_A > 0$, and the first term will be negative.

On the other hand, the profit per unit sold in the downstream market (second term) can decline, especially if the increase in storage capacity raises purchasing costs, which means that the second term could be positive. Whether this will be the case depends on the demand profiles of both suppliers:

$$\frac{\partial(p_A - (1 - x_A)p - x_{AP'})}{\partial K_A} = \alpha_A - \beta_A \frac{\partial z_A}{\partial K_A} - \gamma_{AB} \frac{\partial z_B}{\partial K_A} \quad (81)$$

$$= \frac{\gamma_{AB}(\alpha_A - 3\alpha_B)}{2(4\beta_A\beta_B - \gamma_{AB}^2)}. \quad (82)$$

This expression is negative if and only if $\alpha_A < 3\alpha_B$, or equivalently, $x_A - \frac{1}{2} < 3(x_B - \frac{1}{2})$: we thus retrieve the condition that characterised the cross-effect of supplier A 's storage capacity on the other supplier's sales. If the demand swing is sufficiently large in market B , the price-smoothing effect of additional stocks held by A will lead supplier B to increase his sales, and hence his spot purchases, which in turn will increase the purchasing costs for supplier A . In this case, an increase in K_A will decrease the profit per unit sold in market A .

To summarise, the first bias is positive, and the second bias is the sum of a negative term and a term that can be positive or negative: the sign of the total bias is generally ambiguous. This total bias can be expressed as a function of suppliers' sales:

$$\begin{aligned}\tilde{V} - V_A = & \frac{-1}{4\beta_A\beta_B - \gamma_{AB}^2} \left(\left(\frac{3\alpha_A - \alpha_B}{2} + 3\alpha_A\beta_B \right) (d - b - \gamma_{AB}z_B + \alpha_A K_B) \right. \\ & \left. + 2(4 + (9 - 4\beta_A)\beta_B + \gamma_{AB}^2)K_A \right) + \alpha_A z_A.\end{aligned}\quad (83)$$

Reinjecting the values of z_A and z_B yields

$$\tilde{V} - V_A = \frac{1}{(4\beta_A\beta_B - \gamma_{AB}^2)^2} (\lambda_0(d - b) + \lambda_A K_A + \lambda_B K_B), \quad (84)$$

where

$$\lambda_0 = \frac{1}{4} (2\beta_B - \gamma_{AB}) (-3\alpha_A(2\beta_A - 1)(2\beta_B + 1) - 13\alpha_A + 6\alpha_B) \quad (85)$$

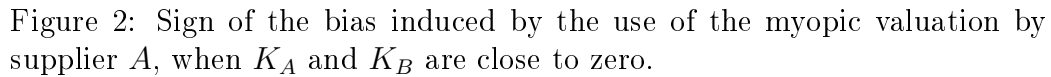
$$\lambda_A = (4\beta_A\beta_B - \gamma_{AB}^2)(12\beta_B - \gamma_{AB}) + 2\beta_B(3\alpha_B - \alpha_A)^2 \quad (86)$$

$$\begin{aligned}\lambda_B = & (4\beta_A\beta_B - \gamma_{AB}^2)(-4 - 6\beta_A + 9\beta_B - \gamma_{AB}) \\ & - \frac{1}{2}\alpha_B(3\alpha_B - \alpha_A)(\gamma_{AB}^2 + 8\beta_A\beta_B) - \beta_B(3\alpha_B - \alpha_A)^2.\end{aligned}\quad (87)$$

$\lambda_A > 0$, but the sign of λ_B is ambiguous: it is generally negative, except for some cases where both x_A and x_B are close to $1/2$. The sign of λ_0 is also ambiguous.

In the case where supplier A envisages investing in additional storage capacities, does the myopic valuation lead him to invest too much or too little? We focus on the situation where supplier A already carries inventories (otherwise, additional investment is not an issue).¹⁵

¹⁵When inequality (??) is not satisfied, A carries no inventories at all; however, it is possible that $\alpha_A + \alpha_B > 0$, so that myopic valuation is positive. In this case, the myopic valuation will overestimate the real value of storage for supplier A . However, it is not realistic to suppose that a supplier will invest if he presently uses no inventories at all.


$$\alpha_A \beta_B + \frac{\alpha_A + 5\alpha_B}{6} > 0,$$

However, these conditions do not guarantee that the myopic valuation would lead the supplier to invest too little (negative bias). For small values of K_A and K_B (including the cases where B does not hold inventories), the sign of the bias is the sign of λ_0 , which is negative if and only if

where the left hand-side is strictly positive, and the right hand-side is negative unless α_B is much higher than α_A . Therefore, for most values of x_A and x_B , the bias will be negative.

However, the bias can be positive when α_A is close to zero (x_A close to $1/2$) and α_B is very large (dark gray area in Figure 2). In such a situation, the strong demand swing in market B leads both suppliers to carry inventories, but despite a positive spot price spread, the fundamentals of demand in market A do not justify an increase in supplier A 's stocks: this increase would make his purchases globally more expensive (as it would push supplier B 's spot purchases upwards, as explained before), whereas it would hardly allow for any additional sales in market A . If supplier A based his investment decision on the sole price spread he would be induced to invest; but an investment would not in fact be profitable for him. In this case, the myopic valuation overestimates the true value of additional capacities (positive bias).

More generally, the bias is more likely to be positive when K_A is large (remember that $\lambda_A > 0$): as in the previous section, the volume effect prevails for a supplier with a large capacity, and the myopic valuation tends to overstate the true value of a capacity expansion.

Conversely, for a wide range of values of x_A and x_B , when x_B is not too large compared to x_A , the bias will be negative (light gray area in Figure 2), which means that using the myopic valuation will lead supplier A to underestimate the true value of a capacity increase, and thus to under-invest.

Proposition 4. *When suppliers buying in the same spot market are active in different downstream markets where they enjoy market power, the value of additional storage capacities for each of them is not equal to the traditional valuation based on spot price arbitrage. The sign of the bias is ambiguous.*

Proposition 5. *The bias is negative (the myopic valuation underestimates the true value) when the demand profile is strongly increasing in both markets, or when it is increasing in the investing supplier's market and is relatively flat in the other supplier's market.*

The bias can be positive when demand in the investing supplier's market is flat but has a strong seasonal swing in the other market.

To conclude, it is possible for the myopic valuation to overestimate the true value of additional storage capacities in some particular cases, *i.e.*, where the demand profile of the investing supplier is rather flat and demand in the other market has a very strong seasonal profile. More often, the bias will be negative, and it will increase as the supplier's own demand exhibits a strong seasonal swing.

5 Conclusion

Most techniques developed for the valuation of real assets (such as storage capacities) related to commodities exchanged on a spot market are based on the modelling of spot prices and the computation of arbitrage profits. These methods consider that all the relevant information is included in these prices; therefore ignoring not only the determinants of supply and final demand of the good, but also the structure of the market, and in particular, the existence of market power. However, even assuming a perfect modelling of spot prices, can real assets be valued correctly if market fundamentals are ignored?

This paper has determined, in a simple setting, the error made by using a passive trading valuation that ignores the market power of storage users, whether they are pure traders or suppliers with downstream customers. Overlooking the volume effect of transactions on the price spread leads to overestimating the stream of trading profits from capacity additions. In addition, the right method for a pure trader is not necessarily well suited for a supplier. Indeed, it will be adequate only if both the upstream and downstream markets are competitive. Otherwise, ignoring downstream profit opportunities leads a supplier to underestimate the real value of storage capacity. Finally, in the case where suppliers active on the same spot market have customers with different demand profiles, the traditional valuation will usually be biased downwards, unless the demand profile of the investing supplier is flat while the demand of other suppliers exhibits a strong seasonal swing.

This systematic bias leads to real-world concern. In the European natural gas market, suppliers have increasingly had to rely on more rigid imports from external producers due to the decline of indigenous production from flexible fields in Northwestern Europe. Höffler and Kübler (2007) estimated that an increase from 25 % to 72 % of working gas volume will be necessary to mitigate the loss of supply flexibility related to this decline. Zwitterloot and Radloff (2009) emphasised the need for appropriate policy measures fostering investment in underground storage facilities to provide sufficient storage capacity for the European gas market. However, the present paper indicates that an unfavourable regulatory environment may not be the only reason that firms are reluctant to invest, in spite of the conspicuous need for additional storage. Suppliers' perceptions of the gains to be expected from new investments might be distorted due to the use of inappropriate valuation methods.

Why would a supplier use the myopic valuation approach to value his storage capacities if it is biased? Presumably, this reflects a lack of necessary information to compute the correct valuation. The traditional techniques only require an accurate forecast of spot prices. While this might be difficult

in general, in a relatively stable market, a model based on past realisations of prices and encompassing some elements related to external shocks (*e.g.*, weather or prices of other commodities) can yield fairly good predictions of future spot prices. Much more information is required to take market fundamentals into account, including detailed data about the market structure, about the supplier's own and other suppliers' final demand and about the storage capacities and costs of all market players. This information is difficult to collect and is sometimes not publicly available. As a consequence, the choice of traditional techniques can be explained by an insufficient knowledge of demand and of the functioning of the market. As all market players become more experienced and this sort of information proves to be relevant for making the right choices, new valuation techniques should be developed that more explicitly take market fundamentals into account.

References

- Barrera-Esteve, Christophe, Florent Bergeret, Emmanuel Gobet, and al. (2006), "Numerical methods for the pricing of Swing options: a stochastic approach", *Methodology and Computing in Applied Probability*, 8, 4, 517–540.
- Carmona, René and Michael Ludkovski (2008), "Pricing Asset Scheduling Flexibility using Optimal Switching", *Applied Mathematical Finance*, 15, 5-6, 405–447.
- Décret n° 2006-1034 du 21 août 2006 relatif à l'accès aux stockages souterrains de gaz naturel, JO n° 0194, 23 August 2006.
- Deng, Shi-Jie (2000), "Stochastic Models of Energy Commodity Prices and Their Applications: Mean-reversion with Jumps and Spikes", University of California Energy Institute Working Paper No. 73.
- Felix, Bastian, Oliver Woll and Christoph Weber (2009), "Gas storage valuation under limited market liquidity: an application in Germany", EWL Working Paper n° 5, Chair for Management Sciences and Energy Economics, University of Duisburg-Essen.
- Gibson, Rajna and Eduardo S. Schwartz (1990), "Stochastic convenience yield and the pricing of oil contingent claims" *The Journal of Finance*, 45, 3, 959-976.
- Höffler, Felix and Madjid Kübler (2007), "Demand for storage of natural gas in north-western Europe: Trends 2005-30", *Energy Policy*, 35, 10, 5206–5219.
- Jaillet, Patrick, Ehud I. Ronn and Stathis Tompaidis (2004), "Valuation of Commodity-Based Swing Options", *Management Science*, 50, 909–921.

- Loi n° 2003-8 du 3 janvier 2003 relative aux marchés du gaz et de l'électricité et au service public de l'énergie, JO n° 3, 4 January 2003.
- Martinez-de-Albéniz, Victor and Josep Maria Vendrell Simon (2008), "A capacitated commodity trading model with market power", Working Paper no 728, IESE Business School-University of Navarra.
- Manoliu, Mihaela and Stathis Tompaidis (2002), "Energy futures prices: term structure models with Kalman filter estimation", *Applied Mathematical Finance*, 9, 21–43.
- Office of Gas and Energy Markets (2009), "Liquidity in the GB wholesale energy markets", Ofgem Discussion Paper 62/09.
- Rademaekers, Koen, Allister Slingenberg and Salim Morsy (2008), "Review and analysis of EU wholesale energy markets", ECORYS Nederland BV report for the European Commission DG TREN.
- Schwartz, Eduardo S. (1997), "The Stochastic Behavior of Commodity Prices: Implications for Valuation and Hedging", *The Journal of Finance*, 52, 923–973.
- Secomandi, Nicola (2009), "On the Pricing of Natural Gas Pipeline Capacity", *Manufacturing and Service Operations Management*, Articles in Advance.
- Sioshansi, Ramteen (2009), "Welfare impacts of electricity storage and the implication of ownership structure", mimeo, Ohio State University.
- Sioshansi, Ramteen, Paul Denholm, Thomas Jenkin and Jurgen Weiss (2009), "Estimating the value of electricity storage in PJM: Arbitrage and some welfare effects", *Energy Economics*, 31, 2, 269–277.
- Thompson, Andrew C. (1995), "Valuation of path-dependent contingent claims with multiple exercise decisions over time: the case of Take or Pay", *Journal of Financial and Quantitative Analysis*, 30, 271–293.
- Zwitzerloot, Reinier and Anke Radloff (2009), "Strategic Use of Gas Storage Facilities", *Handbook Utility Management*, A. Bausch and B. Schwenker (eds.), Springer-Verlag Berlin Heidelberg.

6 Appendix

6.1 Proof of Lemma 2

Proof. From Lemma 1, if at least one supplier carries no inventory, then neither do the traders. Now suppose that all suppliers carry positive inven-

tories and that their storage capacities are not binding. From (18), for all j , $T'(w_j) + \frac{1}{1+r}\alpha z_j = 0$. Summing up over all suppliers and rearranging yields

$$-n(rb + (1+r)c) - (2+r)(n \sum w_i + (n+1) \sum w_j) + (n+1)\alpha \sum z_j = 0. \quad (89)$$

Now suppose that m traders are active in the market with positive stocks: $T'(w_i) \geq 0$ for all i . Summing up over all traders and rearranging yields

$$-m(rb + (1+r)c) - (2+r)((m+1) \sum w_i + m \sum w_j) + m\alpha \sum z_j \geq 0. \quad (90)$$

Multiplying equation (89) by m and equation (90) by $(n+1)$ and then subtracting yields

$$m(rb + (1+r)c) + (2+r)(m+n+1) \sum w_i \leq 0. \quad (91)$$

This is impossible; therefore no trader can be active in the market. \square

6.2 Equilibrium inventories in the case where not all firms are capacity-constrained

Let m_u and n_u denote the number of unconstrained traders and suppliers, and ΣK_{ic} and ΣK_{jc} denote the aggregate stocks of capacity-constrained traders and suppliers, respectively. Combining equations (11), (16) and (19) yields the equilibrium aggregate stocks:

$$\begin{aligned} \Sigma w_i &= \Sigma K_{ic} + \frac{m_u}{\Delta} ((n - n_u)\alpha D - (n+1)\beta C - (n+1)(1+r)(3+r)\Sigma K_{jc} \\ &\quad - ((n+1)(1+r)(3+r) + (n_u+1)\alpha^2)\Sigma K_{ic}), \end{aligned} \quad (92)$$

$$\begin{aligned} \Sigma w_j &= \Sigma K_{jc} + \frac{n_u}{\Delta} \left((m_u + n + 1) \frac{(2+r)\beta}{(1+r)(3+r)} (\alpha D - \beta C) + m_u \beta C \right. \\ &\quad \left. - (n+1)(2+r)\beta \Sigma K_{ic} - ((n+1)(2+r)\beta + m_u \alpha^2) \Sigma K_{jc} \right), \end{aligned} \quad (93)$$

where

$$\Delta = m_u(n - n_u)(1+r)(3+r) + (m_u + n + 1)(n_u + 1)(2+r)\beta. \quad (94)$$

The inventories of one individual unconstrained firm are easily computed: $w_i = (\Sigma w_i - \Sigma K_{ic})/m_u$ and $w_j = (\Sigma w_j - \Sigma K_{jc})/n_u$. Let $\Sigma w \equiv \Sigma w_i + \Sigma w_j$ denote the total inventories carried at equilibrium:

$$\begin{aligned} \Sigma w &= \frac{1}{\Delta} \left(\frac{\Delta - (m_u + n + 1)(2+r)\beta}{(1+r)(3+r)} (\alpha D - \beta C) - m_u \beta C \right. \\ &\quad \left. + (n+1)(2+r)\beta (\Sigma K_{ic} + \Sigma K_{jc}) + m_u \alpha^2 \Sigma K_{jc} \right). \end{aligned} \quad (95)$$

FiME

LABORATOIRE COMMUN
DAUPHINE CREST EDF

Laboratoire de Finance des Marchés de l'Énergie

Institut de Finance de Dauphine, Université Paris-Dauphine

1 place du Maréchal de Lattre de Tassigny

75775 PARIS Cedex 16

www.fime-lab.org