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Storage and Capacity Rights Markets in the Natural Gas Industry

by
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Abstract

This dissertation presents a different approach at looking at market power in capacity rights markets that goes beyond the functional aspects of capacity rights markets as access to transportation services. In particular, this dissertation analyzes the role of storage in limiting the ability of pipelines to extract monopoly rents. The first two chapters present a model that show storage, by intertemporally linking markets, as introducing the pipeline in the valley as a competitor to the pipeline in the peak. As such, storage limits the ability of the pipeline to price monopolistically. This competitive effect is present although the pipeline retains 100% market share. It is thus important that regulators understand that focusing on concentration indices as a measure of market power *overestimates* the extent to which pipeline can extract monopoly rents. This dissertation also focuses on the role of contracts in capacity rights markets. Contracts play a dual role. They not only allow for a stronger competitive effect of storage but they can also lead to more efficient levels of pipeline investments as they can allocate risks more efficiently and can solve the information asymmetry problems. In this sense, contracts and storage should be seen as substitutes to market mechanisms when markets fail. In some instances, this dual role of contracts can be conflicting. Regulators need to understand this dual role of contracts in order to use it as a tool for achieving efficiency in capacity rights markets.

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Introduction

Over the last two decades, dramatic changes have taken place in the industrial structure, ownership forms and regulatory structures governing the natural gas industry. These changes have originated in the United States with a vast pipeline infrastructure, but are quickly spreading to other countries, even to those with limited infrastructure in place. These changes seek to replace the horizontally integrated hierarchy, characterized by pipeline companies buying and selling gas under long term contracts, with governance structures that rely much more on unregulated markets, more diffuse vertical and horizontal ownership arrangements and alternative mechanisms for regulating the "natural monopoly" of pipelines.

In the United States, this restructuring process started with the Natural Gas Policy Act of 1978, which introduced deregulated wellhead prices. This process effectively introduced gas-to-gas competition at the wellhead and led to the development of wellhead spot markets. According to De Vany and Walls (1995), these spot markets are very integrated and transportation costs explain price differentials. We can talk of a single United States wellhead gas market. Through a series of orders in the late 1980s and early 1990s, culminating with Order 636 in 1992, the Federal Energy Regulatory Commission (FERC) completed the restructuring process by separating the merchant and transportation activities of pipelines. Pipeline companies serve now as transportation companies and do not own the gas they transport. End users, when transporting gas from the wellhead to the burner tip, must purchase capacity rights to have access to the

pipeline network, in addition to paying any transportation costs. Furthermore, the introduction of a capacity release program and the flexibility in receipt and delivery points enable a greater standardization of capacity rights and the development of a secondary spot market for capacity rights. In this sense, access to pipeline capacity (e.g. pipeline capacity rights) should be viewed as a tradable asset complementary to gas. The secondary market for capacity rights performs two functions. First, it guarantees an efficient allocation of scarce capacity to those end users that value gas the most; and second, the resulting price represents the value of capacity to end users.

In this new industry structure, decision and ownership rights are completely dispersed and hence decentralized. The different end users decide how much and when to transport gas. In contrast, under the old hierarchy, pipeline companies, as owners of the gas they transported, centralized this decision. Today, end users make their decisions based on the price signals they receive from the wellhead gas and capacity rights markets. Any shift in consumption patterns of a particular end user is a direct response price signal. Thus, an electricity generation company might switch to alternative fuel oil during the winter period when gas prices tend to be relatively high. Moreover, prices under the new structure also provide investment signals. If capacity rights prices are high, they indicate that more capacity is needed and can be added at a profit. In sum, the most important element in the restructuring process in the United States has been the recognition of price signals as guide to efficient consumption patterns and investment levels.

The restructuring process in other countries takes this recognition as the starting point. Countries such as Argentina, Bolivia and Britain introduced gas to gas competition by privatizing and separating vertically and horizontally state owned monopolies. Open access to the pipeline network was also introduced creating a price for capacity rights. Moreover, many regions (including Europe and the Southern Cone) are physically integrating their markets and reaping the benefits of trading[1]. For this

[1] As an illustration, there are numerous pipeline projects in the Southern Cone region. The Bolivia-Brazil pipeline was just recently completed. A pipeline from Argentina into Santiago is scheduled to be

integration to be successful countries must adopt comprehensive and consistent regulatory frameworks centered on markets and price signals, and that respect property rights across borders. The price signals introduced through capacity markets will play a pivotal role in this regional integration process, as they would guide pipeline investments.

It is important that prices be transparent if they are to guide consumption patterns and investments efficiently and maximize social welfare. This dissertation concentrates on the capacity rights price. It focuses on two sources for the non-transparency of capacity prices. First, in some markets, pipelines are monopolistic and as such are bound to exploit their position if left unregulated when determining capacity rights prices. Monopolistic prices are necessarily higher than the competitive price and lead to inefficient consumption patterns as end users might switch to alternative sources of energy when in a competitive world it would be inefficient to do so. Second, in the context of infant markets with limited infrastructure in place such as the Southern Cone market, capacity rights prices might not only be not transparent, but more importantly *non-existent*. What is the capacity rights price for the pipeline linking Bolivia and Northern Chile if there is no gas flowing to the region? How much capacity to build? Even if there are answers to these questions, other market imperfections might hinder efficient investments. In particular, differences in the ability to bear the risks involved in developing gas pipeline projects could potentially lead to the failure to develop projects that are economically attractive from a social point of view, but unattractive to one of the parties.

This dissertation addresses these two issues. In particular, the dissertation argues that contracts between end users and the pipeline on the one hand, and storage on the other hand, play an important role in limiting the monopoly power of pipelines and in inducing efficient pipeline investments. Although regulation, with its usual limitations in dealing with informational asymmetries[2], can still play an important role, this dissertation

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completed next year. Other projects include two Argentina-Chile pipelines, one Bolivia-Northern Chile, one Argentina-Brazil and one Bolivia-Paraguay.

[2] See Laffont and Tirole (1993) for a comprehensive theoretical treatment on this issue.

argues that contracts and storage provide market-based mechanisms to limit market power. As such, contracts and storage should be seen as complementary to regulation. The dissertation also argues that contracts are an important element in the development of pipeline projects by allocating risks and returns in an efficient manner and by providing the right incentives for efficient behavior for all parties and information sharing. That is, in the Coasian tradition, this dissertation views contracts and storage as substitutes to market mechanisms when markets fail.

This dissertation borrows heavily from the industrial organization literature in economics. It relies on mathematical models where the pipeline maximizes profits subject to some constraints introduced by the nature of the contracts and storage. It also borrows from the contract theory and incomplete contract literature in determining how contracts can induce efficient behavior and information sharing. From the applied corporate finance literature, the dissertation borrows on how different contracting mechanisms can allocate risks more efficiently.

The role of capacity rights markets for the allocation of scarce infrastructure capacity has been extensively discussed in the economics literature in the context of the restructuring of the electricity sector. This dissertation borrows many of the concepts expanded in this literature. Tabors and Wilson (1999) propose an auction based allocation of firm capacity rights in the electricity market. They further propose these rights be traded on a secondary market at market determined prices. The proceeds of the auction are proposed to go to transmission companies. The capacity rights market assumed in this dissertation is similar to that in Tabors and Wilson in that the pipeline auctions rights and these are traded on a secondary market. However, in contrast to their proposal, this dissertation focuses on the ability of pipelines to extract monopoly rents and thus to affect the number of rights to be issued. Tabors and Wilson assume that the transmission company does not have the power to alter the number of rights issued. The emphasis of the paper is on the design of an auction process that would ensure a fair and efficient allocation of rights to those end users that value it most. In contrast, this dissertation focuses on storage as an alternative mechanism to limit the ability of

pipelines to extract monopoly rents while neglecting altogether the issue of allocation among the different end users.

Similarly, Joskow and Tirole (1999 a, b) study capacity rights markets in the electricity sector and focus on the allocation of transmission rights may enhance the market power of sellers or buyers. As Tabors and Wilson, they assume the number of capacity rights is given (maybe by regulators) and that transmission companies have no power altering this number. Interestingly, their paper recognizes that the ultimate allocation of rights is endogenous and depends on the microstructure of the rights markets. This dissertation borrows this insight and argues that the ability of pipelines to extract monopoly rents depends on the microstructure of capacity rights markets, in particular the contracting regime.

Many of the studies on capacity rights markets in the electricity sector can easily be extended to the natural gas sector. However, this dissertation takes the storability characteristic of natural gas and analyses its effect on capacity rights markets. Because electricity is not fully storable[3], the literature on capacity rights markets in the electricity market does not provide a complete understanding of the issues in the natural gas sector. The role of storage in commodity prices has also been widely studied in the economics literature. The assumption in these studies is that storage is operated by producers. Pindyck (1990), for example, argues that storage can serve to smooth production during periods of low prices, but they play an important role if facilitating production and avoiding stockouts during periods of high prices. This would be a valid assumption under the old structure of the natural gas industry where pipelines sold the gas to end users. Pipelines, thus, used storage to decrease investment and purchasing costs. Moreover, they internalized this storage effect on their pipeline throughput decision. In contrast, under a deregulated natural sector this assumption is no longer valid. Now end users must coordinate their purchases of capacity rights and storage services. Under the new structure, storage does not only serve to smooth gas delivery costs to end users, but

[3] Electricity can be stored in the form of pumped storage, but this storage capacity is very small in relation to electricity demand.

more interestingly, it serves to bypass the capacity rights market altogether. Pipelines cannot fully internalize any longer the storage decision.

This concept of storage as a mechanism to bypass capacity rights market differentiates the treatment of storage in this dissertation from that in the economics literature. This bypass concept is also exploited in Laffont and Tirole (1996 a) in the context of pollution permits. Their paper analyze the impact spot and futures markets for tradable pollution permits on the potential polluters' compliance decisions. Potential polluters can bypass the permits by investing in pollution abatement. This investment is equivalent to storage in the analysis presented in this dissertation. The model presented here borrows from their treatment of spot markets and future markets and their effects on bypass decisions.

The structure of the dissertation is as follows. The first two chapters give theoretical and mathematical models of how contracts between end users and pipelines, and storage limit the ability of a pipeline to extract monopoly rents. Three contract structures are analyzed. They differ in their ability to sell forward and to distinguish between peak and valley periods. The first chapter analyses the case of certainty and the second chapter analyzes the impact of uncertainty. The third chapter analyzes the role of contracts in the development of pipeline projects. In particular, it identifies the different risks involved and analyzes how different contracting mechanisms can yield an efficient allocation of these. This chapter focuses on the relationship and interaction between contracts and infrastructure in place at the time of the investment. In particular, it discusses how contract features change as a function of infrastructure. These three chapters can each be considered as self contained, and can be read independently of the others. Finally, the conclusion of the dissertation discusses some policy recommendations as well as future research based on the analysis presented here.

Chapter 1:

Capacity Rights, Contracts and Storage with Certainty

1.1. Introduction

The natural gas industry in the United States has gone through dramatic changes in the last two decades that culminated with FERC's Order 636 in 1992. These changes aimed at differentiating potentially competitive segments from network infrastructure segments. They also aim at guaranteeing suppliers in the competitive segments a fair and equal access to the network segments in order to supply their services in competitive environment. Order 636 separated the merchant and transportation activities of pipelines and introduced a secondary market for capacity rights. End users must coordinate their gas purchases with purchases of transportation rights in order to guarantee their supply at the burner tip. In this sense, access to pipeline network should be seen as a tradable and complementary asset to gas. Although some considerations, such as price, caps currently limit the transparency and efficiency of the secondary markets for capacity rights, the industry is evolving towards market-determined prices for capacity rights.

The question that arises is that many regions are served by a single pipeline which is bound to exploit its position if left unregulated in determining the prices for capacity rights. Regulation is necessary to avoid monopoly rents by the pipeline. However, this paper argues that storage and contracts can be used in conjunction with regulation in limiting the ability of the pipeline to extract monopoly rents. The model presented here is general enough that it can be extended to other private monopolists facing a seasonal demand and end user bypass in the form of storage. The main impact of storage is that, by allowing end users to bypass the pipeline, it introduces competition to the pipeline in the peak. End users will make their by pass decisions based on their expectations of the difference between peak and valley prices.

The extent of this competitive effect of storage and the extent that the monopolist pipeline can limit it will greatly depend on the market structure of the capacity rights market. Here we analyze three possible market structures: (i) a long term contract structure where the pipeline can make and commit to forward sales of capacity rights, (ii) a short term contract structure where the pipeline sells capacity rights at the beginning of the each period, and (iii) a contract structure by which end users have the right to transport *at any point in time*, up to the maximum throughput amount their capacity right allows. The first two structures entail a separate right for valley and peak times. End users will have a right to transport gas during the valley which is not the valid for the peak. Because of seasonalities in demand, end users will buy more rights during the peak than the valley. In contrast, the third structure makes no distinction between rights for valley and peak times; they are equivalent[4] as the number of capacity rights is equal in both valley and peak times. End users can transport up to a fixed amount at any point in time. Depending on the magnitude of the seasonality, end users may find themselves with over capacity during the valley. It is important to note that the US market under Order 636 resembles the third contract structure described above.

The model analyzes two scenarios. The first assumes that pipeline infrastructure is already in place and hence sunk, and that capacity is *not* binding in the peak. Under

[4] From here on we shall refer to this third structure as "EQ" for "equivalent".

this scenario, the model shows that storage unambiguously increases social welfare under the three market structures. However, this positive impact of storage is greater with a short term contract structure than with a long term structure. The latter allows the pipeline to more effectively limit the competitive effect of storage than does the former. This is so because, through forward sales, the monopolist pipeline incorporates the long run elasticity of demand into its maximization problem. That is, forward sales allow the monopolist to incorporate not only the effects of valley prices but also of peak prices on end-users' decision to bypass the pipeline in peak times and its effect on valley profits. With a short term contract structure, however, the pipeline monopolist does not fully internalize the effect of peak prices on valley profits as the monopolist's problem in the peak takes the valley price as given.

Interestingly, the impact of storage under the third market structure can be the smallest or the largest of the three structures depending on the magnitude of the seasonality. With high seasonalities, the monopolist maximizes profit by making capacity bind in the peak and allowing over capacity in the valley. As a result, price in the valley is zero, providing an incentive for storage and hence price in the peak must fall to offset this incentive for storage. The result is lower prices in both the peak and the valley relative to the short term structure. In contrast, with low seasonalities, the monopolist maximizes profits by making capacity bind in both the peak and the valley. The total number of rights issued is between the number of rights issued for the peak and the number issued for the valley under the long term contract structure. As a result, the third market structure leads to a higher price in the peak and a lower price in the valley, and hence to a smaller welfare effect relative to the long term structure.

The second scenario assumes no infrastructure and hence analyzes the investment decision by a monopolist pipeline. As in the first scenario, storage unambiguously increases social welfare under the three market structures. However, the long term and short term market structures lead to the same result. This is so because, when determining the investment level, the monopolist pipeline effectively sells capacity rights forward for the peak period. In other words, the ability to sell forward which was lost under the short term structure in the first scenario, is regained through the investment

decision. Similarly, we also find that the impact of the third market structure is smaller than the other structures for small seasonalities, and is higher for large seasonalities.

The model also shows that the positive impact of storage on welfare depends on the relative length of the peak and the valley. A long peak means there are limited opportunities to inject gas into storage as the valley is relatively short. Consequently, the use of storage facilities is low. By the same token, a long valley means there are ample opportunities to inject gas into storage but the potential benefit of this storage is limited as the peak is relatively short. Again, the use of storage facilities is low. We show this in the context of the first scenario and a long term contract.

The policy implications of the results of this model are very important. First, storage is an important, albeit imperfect, element to undermine the monopolistic position of a pipeline. Regulators, instead of concentrating on devising mechanism to regulate pipelines, can introduce competition by promoting investments in storage facilities (for example by reducing the transaction costs associated with the approval of storage investment plans). Second, the current structure of the US capacity rights market might not be optimal. For those markets with a relatively low seasonality, social welfare would be increased if a short term contract structure is introduced. Third, infant natural gas markets such as the Southern Cone, can develop more efficiently if incentives for storage investments are in place as well as a capacity rights market that promotes social welfare based on the magnitude of seasonality, as argued in this paper.

The second section of the chapter will describe the model as well as the effect of storage on throughput demand. The third section will analyze the first scenario that assumes a pipeline infrastructure in place and no capacity constraints. This section will also evaluate the welfare effects of the three market structures. Finally, the fourth section will analyze the investment decision of a monopolist pipeline and the welfare implications.

1.2. The Model

The model assumes a single period divided into a valley component of duration (1-α) and a peak component of duration α. At an instant dt of time, end-user natural gas demand is given by:

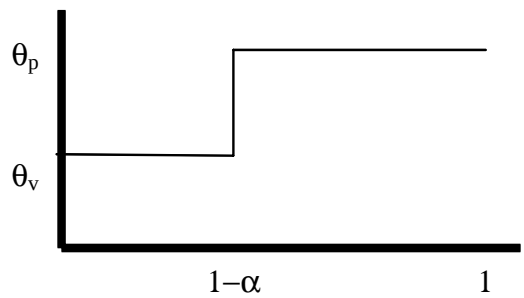
$$q_t = (\theta_t - \gamma P_t)$$

for t=v,p, denoting whether dt is during valley or peak times. θ_t represents the seasonal component of end-user demand. We assume

$$\theta_p = a\theta_v$$

with a>1. We assume α to be in the range (0,1). Figure 1.1 below depicts the time pattern of θ_t.

Figure 1.1: Time Pattern of θ_t



In the context of the current structure of the US natural gas sector, the price P_t paid by end-users has three components. End users pay P_{gt} for gas at the wellhead, a regulated transportation price P_{tt} to get the gas from the wellhead to the city gate, and a transportation capacity reservation price P_{ct}/n, where n represents the instantaneous capacity turnover rate. P_{ct} is paid to reserve one unit of capacity for a given period of time and n represents the number of times this capacity is utilized over the period. That is, $P_t = P_{gt} + P_{tt} + P_{ct}/n$. In order to isolate the effect of storage on capacity rights markets and to simplify our model, we assume an infinitely elastic wellhead gas supply curve and we normalize, $P_{gt}=0$. Also, we assume that the marginal cost of transporting gas is constant, c_p, and that transportation price is regulated at this marginal cost. For simplicity, we normalize such that $P_{tt}=c_p=0$. Finally, we assume n=1. Hence, seasonal component of demand and the effect of storage are totally reflected on the capacity price.

We assume that the pipeline sector is monopolistic. This case can be thought of as a single pipeline delivering gas to a particular consumption center. We assume storage is located at the city gate and is perfectly competitive. This case can be thought of as multiple storage facilities near a consumption center with end-users having equal access to them. Gas is assumed to be injected during the valley period and withdrawn during the peak period. End users make their storage decision to take advantage of price differentials between peak and valley prices, buying pipeline capacity in the valley and transporting gas to the storage location for use in the peak.

We assume complete certainty about future outcomes, and for simplicity, we neglect interest rate. Thus, the price of storage is given by the no arbitrage condition:

$$P_s = P_p - P_v$$

Cost of *total gas injected* into storage, Q_s, is assumed to be quadratic:

$$C_s(Q_s) = \frac{1}{2} c_s Q_s^{\ 2}$$

This assumption is consistent with the operation and investment in natural gas storage facilities. First, because of the compressibility of gas, operational marginal cost of storage increases with the amount of gas inside the storage facility. Injecting an extra unit of gas becomes more expensive because of the associated increase in pressure inside the facility. In contrast, the marginal cost of storing liquids (e.g. oil) is relatively constant. Because of the non-compressibility of liquids, there is no change in pressure inside the storage facility resulting from an extra unit of liquid being stored. Second, most common storage facilities are depleted gas fields and salt caverns[5]. As such, the natural characteristics of these fields and caverns determine the capacity volume of these storage facilities in contrast to containers (e.g. tanks) where investments in surface areas determine the volume of the storage facility. As such, the economies of scale, displayed in container investments where volume increases faster than surface area, are not present in the investment in depleted fields and salt caverns. Investment costs for depleted fields

[5] The investment costs required for liquefied natural gas storage facilities are prohibitively expensive. This is so because of the liquefaction and gasification process required for this type of storage facility.

and salt caverns vary linearly with volume. In sum, the investment and operation costs of natural gas storage facilities can be proxied by a quadratic function.

Equilibrium in the storage sector entails[6]

$$c_s Q_s = P_s$$
$$Q_s = \frac{P_p - P_v}{c_s}$$

Pipeline investments are made at time t=0, and we assume they are immediately available for use. Investment costs are assumed to be linear in capacity, with a constant marginal investment cost of k.

The Effect of Storage on Demand Elasticity

We assume that injections into storage during valley times, and withdrawals from storage during peak times are at a constant, albeit different, rate.[7] That is, during the valley period, instantaneous injections into storage equal:

$$q_s = \frac{Q_s}{1-\alpha}$$

Similarly, during the peak period, instantaneous withdrawals from storage equal:

$$q_s = \frac{Q_s}{\alpha}$$

Thus, in the context of storage, we can define the *throughput* demand curve the monopolist pipeline faces. Throughput demand is defined as end user demand plus the effect of storage (an injection in valley times and a withdrawal in peak times)[8]. The pipeline operator faces the following throughput demand for valley and peak times, respectively:

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[6] Note that in the context of certainty, under a rational expectation equilibrium, total amount *injected* into storage equals total amount *withdrawn* from storage.

[7] This is a direct consequence of neglecting interest rate. With a positive interest rate, end users would want to reduce their interest expenses and would thus try to inject as late as possible in the valley period and to withdraw as early as possible in the peak period.

[8] In the absence of storage, throughput demand is equal to end user demand.

$$q'_v = q_v + \frac{Q_s}{1-\alpha}$$
$$= \frac{1}{c_s}\left[\theta_v c_s + \frac{P_p}{1-\alpha} - \frac{P_v}{1-\alpha}\left(c_s\gamma(1-\alpha)+1\right)\right]$$

and

$$q'_p = q_p - \frac{Q_s}{\alpha}$$
$$= \frac{1}{c_s}\left[\theta_p c_s + \frac{P_v}{\alpha} - \frac{P_p}{\alpha}\left(c_s\gamma\alpha+1\right)\right]$$

Proposition 1.1:

Storage makes peak throughput demand more elastic. The effect of storage on valley throughput demand elasticity is ambiguous.

Proof

In the absence of storage, the instantaneous throughput demand elasticity is equal to the instantaneous end-user demand elasticity, given by

$$\left|\varepsilon_t\right| = \frac{\gamma P_t}{dq_t}$$

for t=v,p. With storage storage, the instantaneous throughput demand elasticity for peak times is equal to:

$$\left|\varepsilon'_p\right| = \frac{\left(c_s\gamma\alpha+1\right)\frac{P_p}{c_s\alpha}}{q'_p}$$

Thus, we have:

$$\left|\varepsilon'_p\right| - \left|\varepsilon_p\right| = \frac{P_p}{c_s\alpha \cdot q'_p \cdot q_p}\left[c_s\gamma Q_s + q_p\right] > 0$$

We note that the above condition holds because:

$$c_s\gamma Q_s + q_p > 0$$
$$\Rightarrow \theta_p - \gamma P_v > 0$$

This condition is equivalent to peak throughput demand having a lower price intercept than peak end user demand. Indeed, we expect this because, given a peak price, throughput demand is lower as a result of storage withdrawals. This difference in peak price intercept is given by:

$$\frac{\theta_p}{\gamma} - \frac{1}{c_s\gamma\alpha + 1}\left[\theta_p c_s \alpha + P_v\right] = \frac{1}{\gamma(c_s\gamma\alpha + 1)}\left[\theta_p - \gamma P_v\right]$$

By the same token, with storage, the instantaneous throughput demand elasticity for valley times is equal to:

$$\left|\varepsilon'_v\right| = \frac{\left(c_s\gamma(1-\alpha)+1\right)\dfrac{P_v}{c_s(1-\alpha)}}{q'_v}$$

Thus, we have:

$$\left|\varepsilon'_v\right| - \left|\varepsilon_{vp}\right| = \frac{P_v}{c_s(1-\alpha)\cdot q'_v \cdot q_v}\left[q_v - c_s\gamma Q_s\right]$$

Similarly, the condition:

$$dq_p - c_s\gamma Q_s = \theta_v - \gamma P_p > 0$$

entails that valley throughput demand have a lower price intercept than valley end user demand. There is nothing in our model that guarantees this. Our model requires (in order to have positive storage injections during valley times) that throughput demand have a higher *quantity* intercept than end user demand, which is indeed what we have for a positive P_p. That is, the effect of storage on valley throughput demand elasticity is ambiguous. A high peak price would lead to θ_v-γP_p >0 and thus an increase in valley throughput demand elasticity. In contrast, a low peak price would lead to θ_v-γP_p <0 and thus a decrease in valley throughput demand elasticity.

Q.E.D.

Intuitively, storage makes peak throughput demand more elastic because, as noted earlier, storage effectively introduces the pipeline in valley times as a direct competitor to the pipeline in peak times. As a result, peak end users are more sensitive to peak period prices (given valley prices), as they are indifferent from obtaining gas directly through the pipeline or via storage. In contrast, the effect of storage on valley throughput is

ambiguous. In the presence of storage, both valley and peak end users demand capacity rights in valley times. A high peak price (or alternative a high seasonal component, a) tends to decrease valley throughput elasticity. Indeed a higher peak price drives peak end users to store more gas increasing the valley throughput demand. At a given valley price, this increase in storage demand leads to a lower elasticity of throughput demand. In contrast, a low peak price results in a low demand for storage. For such low peak prices, small increases in valley prices can eliminate that demand for storage making valley throughput demand very sensitive to valley prices.

Figure 1.2 shows the instantaneous throughput demand and end user demand for both peak and valley times. The first thing to note is that storage renders throughput demand flatter in both valley and peak periods for all values of α. Peak throughput demand is steeper than valley throughput demand for $\alpha>1/2$ (Figure1.2 depicts the case of $\alpha=1/2$, and thus storage injection and withdrawal rates are equal). We also note that peak throughput and end user demand curves intersect at $P_p = P_v$ (taking P_v as given), and in valley times they intercept at $P_v = P_p$ (taking P_p as given). Figure 1.2 depicts the case of a sufficiently low peak price that there is a decrease in valley throughput demand elasticity.

Proposition 1.2:

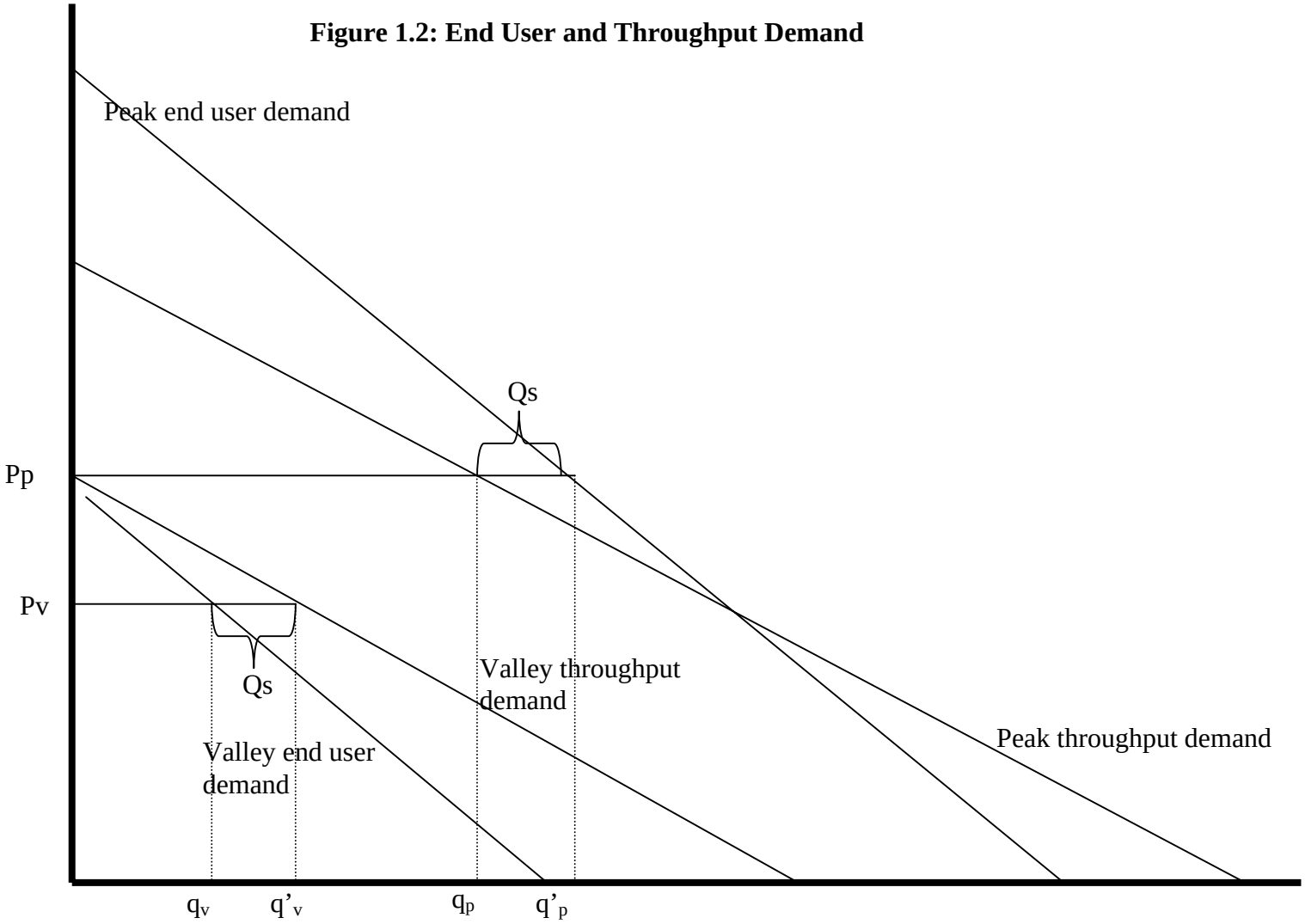
A higher seasonal component of demand, α, decreases the increase in the elasticity of peak throughput demand resulting from storage. The effect on the elasticity of valley throughput demand is a strengthening of the storage effect.

Proof

We calculate the partial derivative of the throughput demand elasticity, with respect to the seasonal component of demand. In the case of peak throughput demand, we have:

$$\frac{\partial\left[\left|\varepsilon'_p\right| - \left|\varepsilon_p\right|\right]}{\partial\alpha} = \frac{-P_p\left(c_s\gamma Q_s + q_p\right)}{c_s q_p}\frac{q_p}{\left[\alpha q_p - Q_s\right]^2} < 0$$

Figure 1.2: End User and Throughput Demand



That is, the effect is unambiguous and is opposite of the storage effect: An increase in α decreases the increase in demand elasticity. In the case of valley demand, we have:

$$\frac{\partial\left[\left|\varepsilon'_v\right| - \left|\varepsilon_v\right|\right]}{\partial\alpha} = \frac{P_v\left(q_v - c_s\gamma Q_s\right)}{c_s q_v}\frac{q_v}{\left[(1-\alpha)q_v + Q_s\right]^2}$$

That is,

$$sign\left[\frac{\partial\left[\left|\varepsilon'_v\right| - \left|\varepsilon_v\right|\right]}{\partial\alpha}\right] = sign\left[\left|\varepsilon'_v\right| - \left|\varepsilon_v\right|\right] = sign\left[q_v - c_s\gamma Q_s\right]$$

Q.E.D.

In sum, the model presented here shows storage as introducing competition to the pipeline in peak times. This competitive effect is described by the increase in the elasticity of peak throughput demand. The model also presents the length of peak times, α, as affecting this competitive effect. However, the underlying structure of the capacity rights market can also affect this competitive effect. In particular, a long term contract structure will tend to undermine this competitive effect in relation to a short term contract structure. The next paragraphs will analyze these considerations.

1.3. Infrastructure in Place

We assume that pipeline infrastructure is monopolist and already in place and hence is sunk[9]. Furthermore, we assume that the capacity of this infrastructure is very large so there are no capacity constraints. This assumption represents the "worst case scenario" as it represents the maximum amount of monopoly rents that a pipeline can extract, as capacity constraints would necessarily decrease monopoly rents. In this context, the monopolist pipeline problem is to determine the amount of capacity rights to sell. In the context of a long term contract and short term contract structures the amount of capacity rights sold in the peak and in the valley are not equal. Physically, a pipeline operator can vary the capacity on its line by increasing or decreasing the pressure inside

[9] Alternatively, we can think of the cost of infrastructure investment as being zero.

the pipe. In this context, we assume that the physical strength of the pipeline is very large and able to withstand high pressures so that capacity constraints do not become a consideration in the peak.

To start building intuition about how contract structures affect the ability of a pipeline to extract monopoly rents, we will first analyze the case with no storage, and later analyze the storage case.

1.3.1. The No Storage Case

In the absence of storage, there is no linkage between peak and valley markets. Prices in both markets are correlated insofar as their demands are correlated. We will first analyze the long term contract structure, then the short term contract structure and last the equivalent contract structure.

1.3.1.1. The Long Term Contract Structure

In this market structure, the monopolist sells *at the same time* capacity rights for both valley and peak times. That is, when selling capacity rights for valley times, the monopolist sells forward capacity rights for peak times. There might be a secondary market for these contracts, as is currently the case in the US with the introduction of the capacity release program under FERC Order 636. In the context of this model, such secondary market guarantees that only high value end-users end up with the capacity rights. It does not affect the number of rights in the valley and in the peak.

The optimal mechanism consists in setting a price P_t or in choosing a number of capacity rights q_t so as to maximize monopolist profits (There is no distinction between these two mechanisms in our model. We will think of the mechanism as a price mechanism in the presence of storage) [10].

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[10] Of course, the monopolist might choose a non-linear pricing scheme to extract more rent from end-users. This chapter does not consider such non-linear scheme for two reasons. First, in the context of natural gas sector, these non-linear schemes are not sustainable. There is nothing in the gas sector that would prevent low price end users to sell their rights at a profit to high price end users in a secondary market. And

$$\underset{P_t}{Max}(\theta_t - \gamma P_t)P_t$$

The solution is given by:

$$P_t^{LT} = \frac{\theta_t}{2\gamma}$$

$$q_t^{LT} = \frac{\theta_t}{2}$$

This is classic monopolist problem. The monopolist tries to restrict output (in this case, capacity rights) so as to increase the price. In the absence of storage, the pipeline fully extracts monopoly rents. We note that the monopolist pipeline prices capacity rights at the point where elasticity of throughput demand is 1.

1.3.1.2. The Short Term Contract Structure

In this market structure, the pipeline monopolist sells capacity at the beginning of the valley and of the peak. This structure can be thought as a series of spot markets. Again, there is no linkage between the valley and peak demands. In each market, the pipeline selects capacity so as to maximize profits in each period. The monopolist problem is identical to the one under a long term contract structure. This is summarized in the following proposition:

Proposition 1.3:

In the absence of storage, long term and short term contract structures lead to the same equilibrium: The pipeline fully extracts monopoly rents.

1.3.1.3 The Equivalent Contract Structure

In this third market structure, the monopolist sells capacity rights at t=0. Unlike the other two market structures studied above, capacity rights under this structure are equally valid in peak and in valley times. That is, at any point in time, an end user has the right to transport gas up to the amount of its capacity right. As noted in the introduction, this structure resembles the current situation in the US market. The

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second, even if such schemes were sustainable, their welfare implications are so obvious that regulators will not permit them.

problem the monopolist pipeline faces is to maximize its revenue from the sales of these rights at t=0. The maximum end-users would be willing to pay for these rights is the sum of their value during the valley and the peak. Under this market structure the monopolist effectively sells the pipeline to end-users while still being in charge for its operation. It is important to note that this structure is somewhat similar to the long term contract structure in that the monopolist effectively sells capacity rights for the peak in the forward market. The difference lies in that under the equivalent contract structure, the monopolist cannot sell different set of rights for the peak and valley, restraining the flexibility of the monopolist.

The mechanism consists in the monopolist selecting an amount K of capacity rights to sell at t=0. We consider two cases. The first assumes that K is binding in both valley and peak times; and the second case assumes that K is binding only in peak times. Depending on the magnitude of the seasonality, a, each scenario represents the best possible equilibrium outcome for the monopolist pipeline.

Case 1: K binding in both peak and valley times

Prices are determined such that throughput demand during valley and peak equals K. That is, we have:

$$\theta_p - \gamma P_p = K$$
$$\theta_v - \gamma P_v = K$$

That is,

In equilibrium, the amount end users will pay for these rights is $(1-\alpha)P_v + \alpha P_p$. Thus the

$$P_p = \frac{\theta_p - K}{\gamma}$$
$$P_v = \frac{\theta_v - K}{\gamma}$$

monopolist's problem is:

$$\underset{K}{Max}\, K\left[\frac{(1-\alpha)(\theta_v - K) + \alpha(\theta_p - K)}{\gamma}\right]$$

The First Order Condition (FOC) is given by:

$$(1-\alpha)\theta_v + \alpha\theta_p - 2K = 0$$

and the solution is thus:

$$K^{EQ} = \frac{(1-\alpha)\theta_v + \alpha\theta_p}{2}$$
$$P_v^{EQ} = \frac{\theta_v[1-(a-1)\alpha]}{2\gamma}$$
$$P_p^{EQ} = \frac{\theta_v[a+(a-1)(1-\alpha)]}{2\gamma}$$

We note that we require a positive valley price, that is:

$$\frac{\theta_v[1-(a-1)\alpha]}{2\gamma} > 0$$
$$\Rightarrow a < \frac{1+\alpha}{\alpha} = a^{0*}$$

Case 2: K binding only in peak times

This case holds for a seasonality magnitude greater than the above threshold. In this case, we have P_v=0, and hence the monopolist must maximize profits by pricing monopolistically in peak times. That is, the monopolist problem becomes:

$$\underset{K}{Max}\, K \frac{\alpha(\theta_p - K)}{\gamma}$$

The usual monopolist solution derives:

$$K^{EQ} = \frac{\theta_p}{2}$$
$$P_p^{EQ} = \frac{\theta_p}{2\gamma}$$
$$P_v^{EQ} = 0$$

1.3.1.4. The Welfare Effects of the Equivalent Contract Structure Relative to the Others

The equivalent contract structure introduces a constraint in the pipeline maximization problem. As such, the pipeline is *necessarily* worse off under the equivalent contract structure. However, the net effect on social welfare depends on the level of seasonality.

Case 1: K binding in both peak and valley times

Proposition 1.4:

When seasonality is low, in the absence of storage, the equivalent contract structure yields a lower social welfare than either the long term or short term contract structures.

Proof

Figure 1.3(a) depicts the equivalent contract structure and the long term contract structure (which yields the same result as the short term contract structure). We see that valley price under the equivalent contract structure is lower, whereas the peak price is higher. Indeed, it can be easily checked that:

$$\Delta P_v^{LTEQ} = P_v^{LT} - P_v^{EQ} = \frac{\theta_v \alpha (a-1)}{2\gamma} > 0$$

$$\Delta P_p^{LTEQ} = P_p^{LT} - P_p^{EQ} = -\frac{\theta_v (1-\alpha)(a-1)}{2\gamma} < 0$$

Similarly, we see that:

$$\Delta q_v^{LTEQ} = q_v^{LT} - K^{EQ} = -\frac{\theta_v \alpha (a-1)}{2} < 0$$

$$\Delta q_p^{LTEQ} = q_p^{LT} - K^{EQ} = \frac{\theta_v (1-\alpha)(a-1)}{2} > 0$$

We note that the price and the throughput differentials are equal for α=1/2.

It is clear that valley end user are better off as a result of lower prices and peak end users worse off. By the same token, the monopolist is better off in the valley and worse off in the peak. The net effect, however, is not ambiguous. In valley times, social welfare under the equivalent contract structure is higher by an amount equal to area A. In peak times, social welfare is lower by an amount equal to area B. Thus, net social welfare change[11] is:

[11] Social Welfare here is defined as the sum of consumer surplus and pipeline profits.

$$\Delta SW^{LTEQ} = -(1-\alpha)\left|\Delta q_v^{LTEQ}\right|\left[\frac{1}{2}\Delta P_v^{LTEQ} + P_v^{EQ}\right] + \alpha\Delta q_p^{LTEQ}\left[\frac{1}{2}\left|\Delta P_p^{LTEQ}\right| + P_p^{LT}\right]$$
$$= \frac{3(1-\alpha)\alpha(a-1)^2\theta_v^{\ 2}}{8\gamma} > 0$$

Q.E.D.

With low seasonality, the pipeline maximizes profits by extracting rents in both peak and valley. As such, the number of rights issued under the equivalent contract structure is somewhere in between the number of rights for valley and peak under the long term contract structure. As such, price increases (and social welfare decreases) in the valley but it decreases (and social welfare increases) in the peak. However, the decreased welfare in the valley is more than outweighed by the increase in the peak. It is worth noting that the longer the peak period is, the closer the number of capacity rights issued under the equivalent contract structure will be to the long term contract level for the peak. Conversely, the longer the valley period is, the closer the number will to the long term contract level for the valley.

Case 2: K binding only in peak times

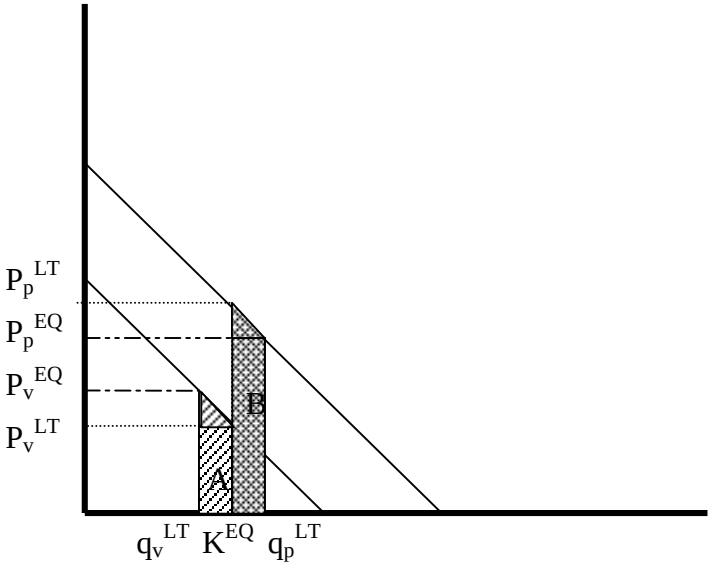
Figure 1.3(b) depicts the equivalent contract structure and the long term contract structure. We note that peak prices remain unchanged under the former relative to the latter, but valley prices decrease to zero. It is clear that the welfare of both end users and the monopolist remain unchanged in the peak, and consequently so does social welfare. In contrast, end users in the valley are better off under the equivalent contract structure and the monopolist worse off. Clearly, the increase in consumer surplus is greater than the decrease in pipeline profits. The equivalent contract structure leads, thus, to an increase in social welfare relative to the long term or short term contract structures. This is summarized in the following proposition.

Proposition 1.5:

When seasonality is high, in the absence of storage, the equivalent contract structure yields a higher social welfare than either the long term or short term contract structures.

Figure 1.3: The Equivalent vs. the Long Term Contract Structures

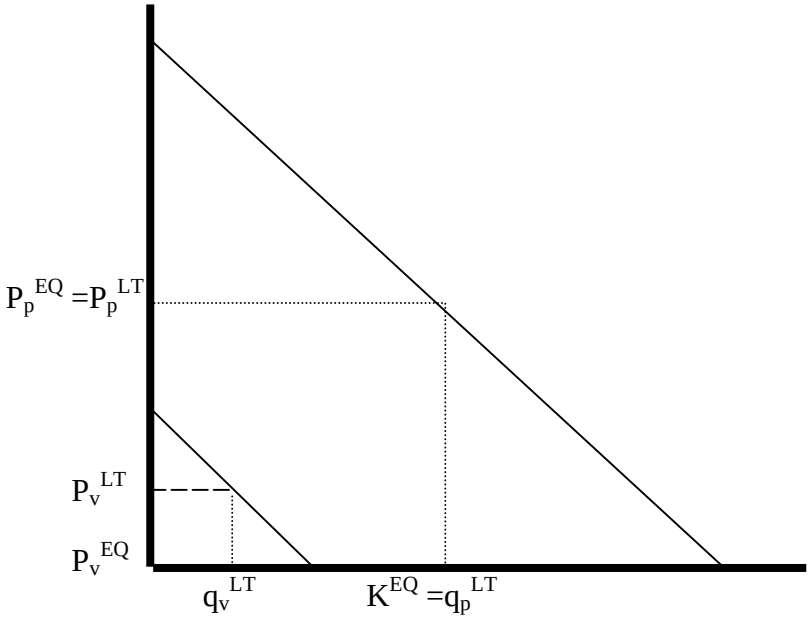
with No Storage



$a<a^{0*}$

Case 1: K binding in both peak and

(a)



$a>a^{0*}$

Case 2: K binding only in peak times

(b)

Propositions 1.4 and 1.5 show that contract do indeed matter in the ability of the pipeline to extract monopoly rents. Here, we saw that an equivalent contract structure necessarily decreases the ability of the pipeline to earn monopoly rents, but the net effect on social welfare depends on the level of seasonality. When storage is introduced, the effect of contracts on the ability of the pipeline to extract monopoly rents is even more dramatic. This is so, because contracts also affect the competitive effect of storage. We will now turn our attention to the storage case.

1.3.2. The Storage Case

As argued earlier, storage introduces a link between peak and valley markets through the arbitrage equation identified in the second part of this chapter. As such, the pipeline must take into account this interaction when determining the number of capacity rights to issue. Again, we will first analyze the long term contract structure and examine the welfare effects of storage as well as the effect of peak duration in the context of this contract structure. We will then analyze the short term contract structure and compare it with the long term contract structure. Finally, we will analyze the equivalent contract structure.

1.3.2.1. The Long Term Contract Structure

Again, this contract structure allows the pipeline to sell capacity rights forward and as such, it allow to take the long run (i.e. peak time) elasticity of demand into account. That is, forward sales allow the monopolist to incorporate not only the effects of P_v, but also of P_p, on end-users' decision to bypass the pipeline in peak times for storage. With this forward sales commitment, the pipeline is able to better "coordinate" the problem it faces in valley and peak times, and as such can more effectively limit the competitive effect of storage. Indeed, the solution to this long term contract structure represents the best that a monopolist can do in the presence of storage

Mathematically, the optimal number of capacity rights in peak and valley times for the pipeline to sell is given by:

$$\underset{P_v, P_p}{Max}(1-\alpha)P_v\left[\theta_v - \gamma P_v + \frac{Q_s(P_p, P_v)}{(1-\alpha)}\right] + \alpha P_p\left[\theta_p - \gamma P_p - \frac{Q_s(P_p, P_v)}{\alpha}\right]$$

and the resulting FOCs for P_v and P_p are, respectively:

$$[(1-\alpha)(\theta_v - 2\gamma P_v)] + \left(\frac{\partial Q_s}{\partial P_v}P_v + Q_s\right) - \left[\frac{\partial Q_s}{\partial P_v}P_p\right] = 0$$

$$[\alpha(\theta_p - 2\gamma P_v)] - \left[\frac{\partial Q_s}{\partial P_p}P_p + Q_s\right] + \left[\frac{\partial Q_s}{\partial P_p}P_v\right] = 0$$

These FOCs show the three effects that a monopolist pipeline must take into consideration when solving this problem:

- The first bracket term of each FOC shows the effect of a change in P_t on valley (t=v) or peak (t=p) total profitability stemming from end user demand.
- The second bracket term of each FOC shows the effect of a change in P_t on valley or peak total profitability stemming from changes in storage usage.
- The third bracket term of each FOC shows the effect of a change in P_t on the other period profitability stemming from changes in storage usage.

The simultaneous solution of both FOCs enables the coordination of the problem facing the monopolist in valley and peak times. Appendix 1.A shows the derivation of the solution of these FOCs, which is given by:

$$P_v^{LT} = \frac{\theta_v(g + a\alpha)}{2\gamma(g+\alpha)}$$

$$q_v^{*LT} = \frac{\theta_v}{2} = q_v^{*LT}$$

$$P_p^{LT} = \frac{\theta_v}{2\gamma(g+\alpha)}[(1-\alpha)c_s\gamma\alpha(a-1) + g + a\alpha]$$

$$q_p^{*LT} = \frac{\theta_p}{2} = q_p^{*LT}$$

where $g=(1-\alpha)(c_s\gamma\alpha+1)$ [12]. The resulting gas amount injected into storage is:

$$Q_s^{LT} = \frac{P_s^{LT}}{c_s} = \frac{\theta_v \alpha(1-\alpha)(a-1)}{2(g+\alpha)} > 0$$

It is important to note the role of commitment in this market structure. Once P_v is set and end-users' storage decision has been made based on the above peak price, the monopolist has the incentive to deviate from the above peak price in peak times. If end-users rationally expect this lack of commitment, they will take it into account when making their storage decisions, and the market structure will end up being a sequence of spot short term transactions which we will analyze later. That is, to distinguish between the short term and the long term contract market structure it is imperative that we assume that the pipeline monopolist credibly commits to forward sales.

The Welfare Effects of Storage

Figure 1.4 depicts the no storage and the storage cases for $\alpha=1/2$ and a long term market structure. The picture depicts valley throughput demand as having a higher price intercept than end-user demand. Thus, the picture shows the case where there is a decrease in the elasticity of throughput demand in the presence of storage. As argued in the second part of this chapter, storage introduces a competitive effect, and thus, we expect social welfare to increase. This is indeed our result, as show in the following proposition.

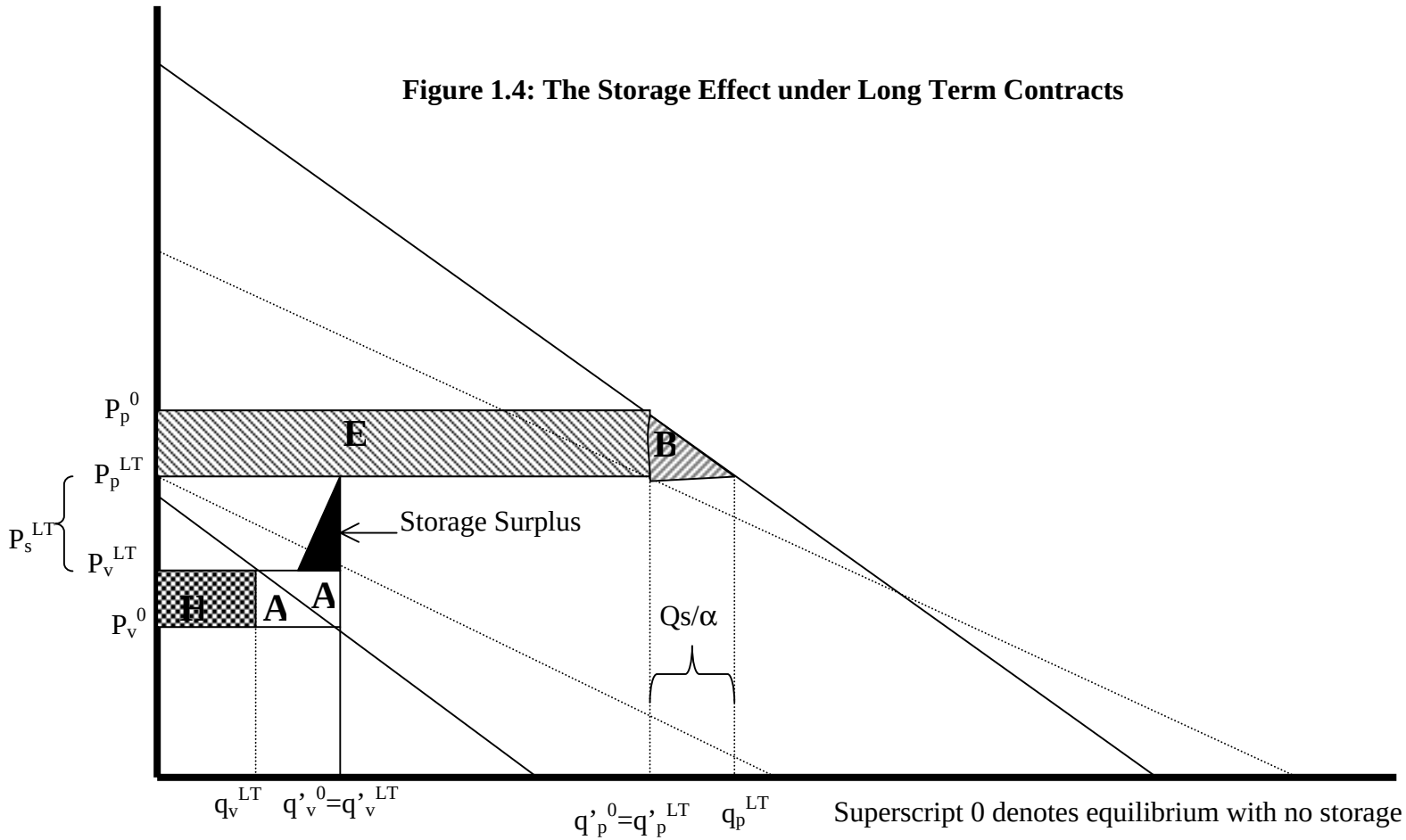
Proposition 1.6:

Storage leads to an increase in social welfare as a result of the competitive effect it introduces.

---

[12] Our expression for valley throughput demand assumes a positive valley end-user demand. Thus, we assume the resulting $P_v^{LT}<\theta_v/\gamma$ or $a<2+g/\alpha$ in order to guarantee an interior solution. There is no lower bound restriction on the value of a.

Figure 1.4: The Storage Effect under Long Term Contracts



Proof

Storage leads to an increase in valley price and a decrease in peak price, as expected. The magnitude of these price changes is given by:

$$\Delta P_v^{LT} = P_v^{LT1} - P_v^{LT0} = \frac{\theta_v \alpha (a-1)}{2\gamma(g+\alpha)} > 0$$

$$\Delta P_p^{LT} = P_p^{LT} - P_p^{LT0} = \frac{-\theta_v (1-\alpha)(a-1)}{2\gamma(g+\alpha)} < 0$$

where the superscript 0 denotes the equilibrium with no storage. Note that the magnitude of price changes are equal for α=1/2.

With these price changes, we can conclude that consumers are unambiguously *better off* as a result of storage. In the valley, consumer surplus is reduced by the sum of areas (H+A) in figure 1.4, and in the peak, consumer surplus is increased by the sum of areas (E+B). The net effect on consumer surplus is thus:

$$\begin{aligned}\Delta CS^{LT} &= -(1-\alpha)\frac{1}{2}\Delta P_v^{LT}\left(2\left(\theta_v - \gamma P_v^{LT}\right) + \gamma \Delta P_v^{LT}\right) - \alpha \frac{1}{2}\Delta P_p^{LT}\left(2\left(\theta_p - \gamma P_p^{0}\right) - \gamma \Delta P_v^{LT}\right) \\ &= \frac{(1-\alpha)\alpha(a-1)^2 \theta_v^{\,2}}{8\gamma(g+\alpha)^2}\left(2(g+\alpha)+1\right) > 0\end{aligned}$$

Similarly, we can conclude that the pipeline monopolist is unambiguously *worse off* as a result of storage. In the valley, producer surplus is increased by the sum of areas (H+2A) in figure 1.4, and in the peak producer surplus is decreased by area E. The net effect on producer surplus is thus:

$$\begin{aligned}\Delta PS^{LT} &= (1-\alpha)\Delta P_v^{LT} q_v^{*LT} + \alpha \Delta P_p^{LT} q_p^{*LT} \\ &= -\frac{(1-\alpha)\alpha(a-1)^2 \theta_v^{\,2}}{4\gamma(g+\alpha)} < 0\end{aligned}$$

The increase in consumer surplus outweighs the decrease in producer surplus. Thus, storage unambiguously increases social welfare in the context of a long term contract market structure. We need to add the surplus in the storage sector to completely obtain an expression of social welfare increase. We have:

$$\Delta SW^{LT} = \Delta PW^{LT} + \Delta PW^{LT} + \frac{P_s^{LT\,2}}{2c_s}$$
$$= \frac{(1-\alpha)\alpha(a-1)^2\theta_v^{\,2}}{8c_s\gamma(g+\alpha)^2}\left(c_s + \gamma\alpha(1-\alpha)\right) > 0$$

Q.E.D.

In sum, we see that by introducing competition to the monopolistic pipeline in peak times and by allowing end-users to bypass the pipeline in peak times, storage leads to an increase in social welfare. Storage hinders the ability of the monopolist to extract rent from end-users. Surprisingly enough, storage does not change the throughput levels in valley and peak times. There is, however, greater consumption in peak times, as a result of a lower peak price, and a lower consumption in valley times as a result of a higher valley price.

The Effect of Peak Length α

First, we note that prices and throughput quantities in the no storage case are unaffected by peak length α. The same holds true for throughput in the case of storage. Changes in α will affect the impact of storage through prices and quantity injected into storage. Intuitively, a longer peak period (i.e. a high α) means the withdrawal rate from storage in peak times is low and peak end-users rely more heavily on pipeline deliveries to meet their demand. That is, a high α limits the competitive effect of storage and thus leads to a smaller decrease in peak price. In contrast, a high α leads to a more important fraction of valley throughput going into storage injection and thus valley price is more closely related to peak demand than to valley demand. That is, a high α makes valley times resemble more peak conditions and hence the introduction of storage leads to a larger increase in valley price. Indeed, we have:

$$\frac{\partial Q_s/(1-\alpha)}{\partial\alpha} = \frac{\theta_v(a-1)(c_s\gamma\alpha^2+1)}{2c_s(g+\alpha)^2} > 0$$
$$\frac{\partial Q_s/\alpha}{\partial\alpha} = -\frac{\theta_v(a-1)(c_s\gamma(1-\alpha)^2+1)}{2c_s(g+\alpha)^2} < 0$$

and

$$\frac{\partial \Delta P_v^{LT}}{\partial \alpha} = \frac{\theta_v (a-1)(c_s \gamma \alpha^2 + 1)}{2\gamma (g+\alpha)^2} > 0$$

$$\frac{\partial \Delta P_p^{LT}}{\partial \alpha} = \frac{\theta_v (a-1)(c_s \gamma (1-\alpha)^2 + 1)}{2\gamma (g+\alpha)^2} > 0$$

The change in amount of gas injected into storage is not, however, unidirectional with respect to α. We have:

$$\frac{\partial Q_s^{LT}}{\partial \alpha} = \frac{\theta_v (a-1)(1-2\alpha)}{2c_s (g+\alpha)^2}$$

Amount of storage injected is maximum when α=1/2. Coincidentally, α=1/2 is also the point where the effect of storage on consumer surplus and producer surplus is maximum since:

$$\frac{\partial \Delta PS^{LT}}{\partial \alpha} = -\frac{\theta_v^{\,2} (a-1)^2}{4\gamma (g+\alpha)^2}(1-2\alpha)$$

$$\frac{\partial \Delta CS^{LT}}{\partial \alpha} = \frac{\theta_v^{\,2} (a-1)^2}{8\gamma (g+\alpha)^3}(1-2\alpha)(g+\alpha+2)$$

We can summarize these observations in the following proposition:

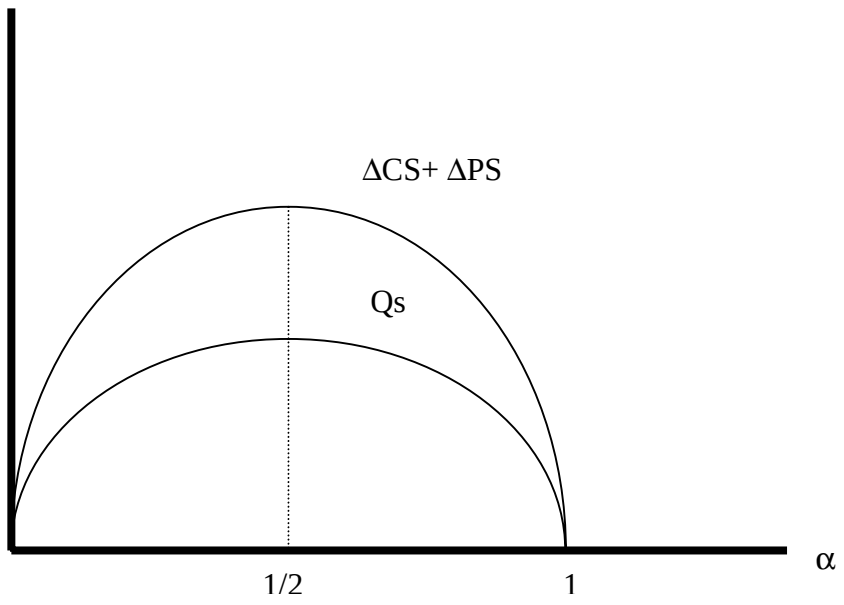
Proposition 1.7

Peak length, α, influences the competitive effect of storage. The competitive effect, measured by change in producer and consumer surplus is concave in α, and maximized when peak and valley periods are of equal length.

Figure 1.5 presents a schematic of the effect of storage on quantity injected into storage, Q_s, and consumer surplus and producer surplus, ΔCS+ΔPS. We see that the competitive effect of storage is limited not only by a high α, but also by a low α. A high α (i.e. a short valley period) limits the opportunities to inject into storage, and hence total amount of gas stored is relatively low, despite the high injection rate during the relatively short valley times. By the same token, a low α (i.e. a short peak period) limits the opportunities to make use of the storage facilities and hence total amount of gas stored is relatively low, despite the high withdrawal rate during the relatively short peak times. The amount of gas stored is maximum when the peak and the valley are equal in length.

At such point, the opportunities to make use of the storage facilities coincide with the opportunities to inject into storage.

Figure 1.5: The Effect of Peak Length



1.3.2.2. The Short Term Contract Structure

The equivalence between long tern and short term contract structures, derived in the case with no storage, is lost in the storage case. In the presence of storage and in contrast to the long term contract structure, a short term contract market does not allow the pipeline to fully internalize the effect of peak price on total profit stemming from the bypass decision of end users for storage. The coordination that was so beneficial to the monopolist pipeline in the case of a long term contract structure is lost here. As a result, in peak times the pipeline can only react to the bypass decision by maximizing peak profits over the residual end user demand, that is, over the demand not already supplied via storage. Hence, the pipeline can less effectively limit the competitive effect of storage. It is in this sense that the pipeline is worse off with a short term contract structure than with a long term contract structure. Conversely, consumers are made better off. Mathematically, we solve the pipeline problem via backward induction.

The peak period problem

The pipeline takes Q_s as given and must maximize over the residual end-user demand. In a rational expectation equilibrium, end-users must anticipate the pipeline's pricing decision in peak times before making their storage decisions in the valley. Thus, equivalently, our pipeline takes Q_s as given, and the optimal peak price is given by:

$$\underset{P_p}{Max}\, \alpha P_p \left[\theta_p - \gamma P_p - \frac{Q_s(P_p, P_v)}{\alpha} \right]$$

Appendix 1.B shows the derivation for the solution to this problem. The solution to this monopolist problem is given by:

$$P_p = \frac{\theta_p \alpha c_s + P_v}{2(c_s \gamma \alpha + 1)}$$

$$q'_p = \frac{\theta_p \alpha c_s + P_v}{2 c_s \alpha}$$

We note that the monopolist sets price at a point where the elasticity of throughput demand is 1. Furthermore, by inspection we see that storage leads to a higher throughput in the peak. This is counterintuitive, as we would expect storage to decrease throughput in the peak. The reason for this result, as we will see later, is that a short term structure is less effective at limiting the competitive effect of storage than a long term contract structure. Also, storage leads to a lower peak price since:

$$P_p^{ST0} - P_p = \frac{\theta_p - \gamma P_v}{2(c_s \gamma \alpha + 1)} > 0$$

where the superscript 0 denotes the equilibrium in the no storage case. The inequality stems from the fact that storage leads to peak throughput having a lower price intercept than end-user demand, indicating withdrawals from storage. The resulting peak total profit level is thus:

$$\Pi_p = \frac{\left[\theta_p \alpha c_s + P_v\right]^2}{4 c_s (c_s \gamma \alpha + 1)}$$

The valley period problem

The optimal valley price is given by:

$$\underset{P_v}{Max}(1-\alpha)\left[\theta_v - \gamma P_v + \frac{Q_s(P_p(P_v),P_v)}{1-\alpha}\right]P_v + \prod_p(P_p(P_v),P_v)$$

The resulting FOC is given by:

$$\left[(1-\alpha)(\theta_v - 2\gamma P_v)\right] + \left[\left(\frac{\partial Q_s}{\partial P_p}\frac{\partial P_p}{\partial P_v} + \frac{\partial Q_s}{\partial P_v}\right)P_v + Q_s\right] + \left[\frac{\partial \prod_p}{\partial P_v}\right] = 0$$

This FOC shows the three effects of a change in P_v that the pipeline operator must take into consideration when solving its valley problem:

- The first bracket term shows the effect on valley total profitability stemming from valley end user demand.
- The second bracket term shows the effect on valley total profitability stemming from changes in storage injection. Note that it takes into account the indirect effect of P_v on storage injection through its effect on P_p.
- The third bracket term shows the effect on peak period profitability stemming from changes in storage injection.

Taking our solution for the peak, the instantaneous throughput demand in the valley is equal to:

$$q'_v = \frac{\theta_v(2g + a\alpha)}{2g} - \frac{P_v\left(2c_s\gamma(1-\alpha)^2 + 1 - 2\alpha\right)}{2c_s g}$$

with $g=(1-\alpha)(c_s\gamma\alpha+1)$; and the above optimization problem becomes:

$$\underset{P_v}{Max}(1-\alpha)dQ'_v P_v + \frac{\left[\theta_p \alpha c_s + P_v\right]^2}{4c_s(c_s\gamma\alpha+1)}$$

Appendix 1.B shows the derivation of the solution to this problem and is given by:

$$P_v^{ST} = \frac{2\theta_v c_s(g+a\alpha)}{4c_s\gamma(g+\alpha)+1}$$

$$q_v^{ST} = \frac{\theta_v}{2}\left[1 - \frac{g+a\alpha}{2g\left(4c_s\gamma(g+\alpha)+1\right)}\right]$$

and the resulting solution for the peak is:

$$P_p^{ST} = \frac{\theta_v c_s \left[a\alpha\left(4c_s\gamma\,(g+\alpha)+3\right)+2g\right]}{2(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]}$$

$$q_p^{ST} = \frac{\theta_v a}{2}\left[1+\frac{g+a\alpha}{\alpha\left(4c_s\gamma(g+\alpha)+1\right)}\right]$$

The resulting gas amount injected into storage is[13]:

$$Q_s^{ST1} = \frac{P_s^{ST}}{c_s} = \frac{\theta_v\left[a\alpha\left(4c_s\gamma g-1\right)-2g\left(2c_s\gamma\alpha+1\right)\right]}{2(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]}$$

The social benefits of short term contracts in relation to long term contracts

Proposition 1.8

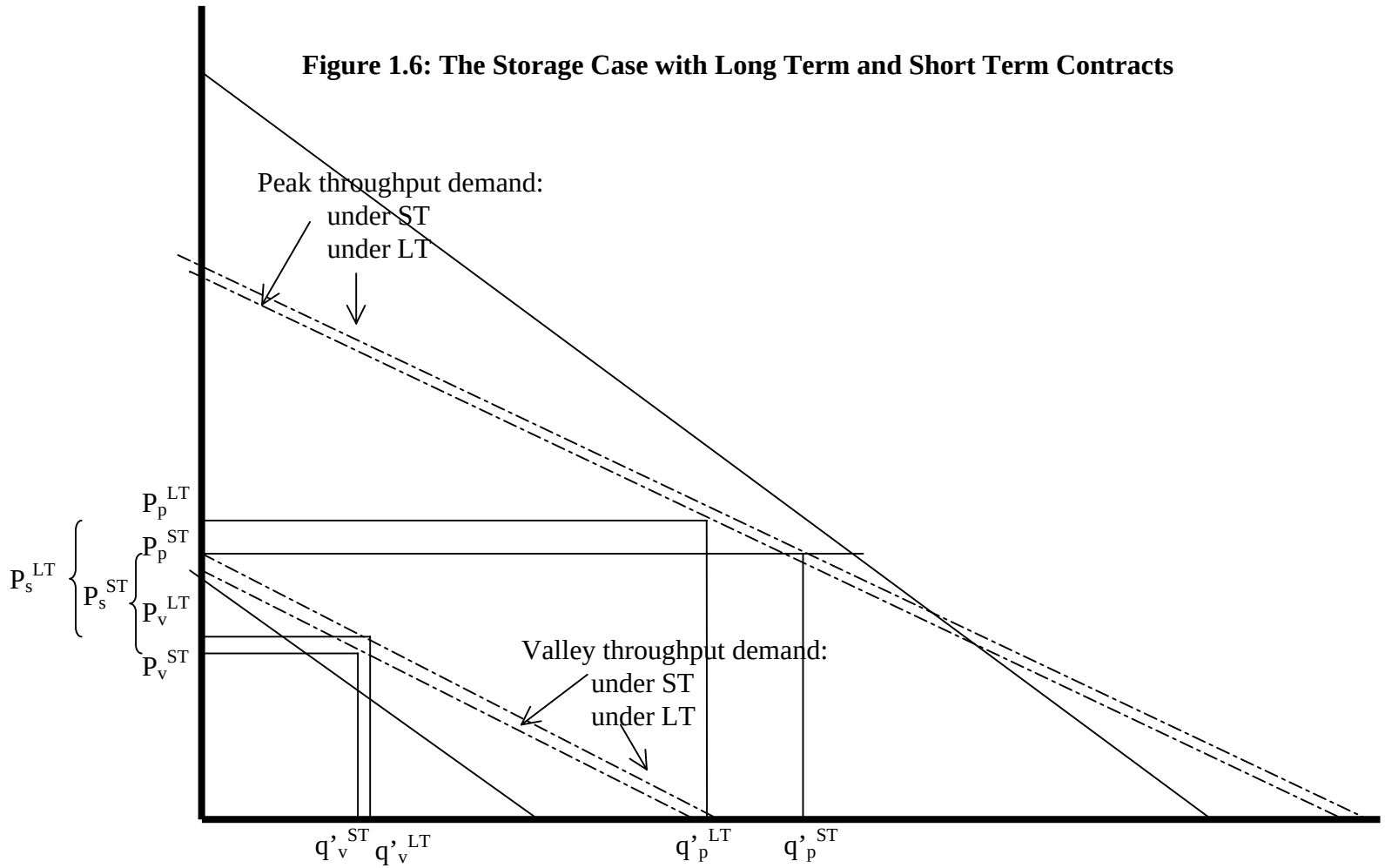
A short term contract structure leads to a stronger competitive effect of storage than a long term contract structure, and as such to a higher social welfare. Following Proposition 1.6, this entails that storage has a positive social welfare effect under short term contracts as well.

Proof

Figure 1.6 depicts the storage case for both short term and long term market structures. We see that in the context of storage, a short term contract structure leads to lower prices both in the peak and in the valley. Indeed, we have:

[13] In order to guarantee an interior solution, we assume $a > \frac{4c_s\gamma+2}{4\alpha c_s\gamma-\frac{\alpha}{g}}$ to insure a positive amount of gas injected into storage, and $a<2+g/\alpha+1/(2c_s\gamma)$ in order to guarantee a positive end user demand, or $P_v^{ST}<\theta_v/\gamma$. Note that this upper condition is already satisfied by our assumption to guarantee an interior solution in the context of a long term contract structure.

Figure 1.6: The Storage Case with Long Term and Short Term Contracts



$$\Delta P_v^{LTST} = P_v^{LT} - P_v^{ST} = \frac{\theta_v(g + a\alpha)}{2\gamma(g+\alpha)\left[4c_s\gamma(g+\alpha)+1\right]} > 0$$

$$\Delta P_p^{LTST} = P_p^{LT1} - P_p^{ST} = \frac{\theta_v(g + a\alpha)}{2\gamma(g+\alpha)\left[4c_s\gamma(g+\alpha)+1\right]} \frac{\left(2c_s\gamma(g+\alpha)+1\right)}{c_s\gamma\alpha+1} > 0$$

We note that the peak price differential is larger than the valley price differential. Hence we conclude that short term contracts entail a lesser usage of storage facilities than long term contracts. Furthermore, by inspection of our short term contract structure results, we see that throughput demand in the peak increases whereas throughput demand in the valley decreases relative to the long term contract structure.

The question is what these observations entail for social welfare. Consumers are clearly better off with a short term contract structure since it entails lower prices. The monopolist pipeline is worse off because, as argued earlier, a short term contract does not give the flexibility to coordinate the monopolist's problem in the peak and in the valley. The best that the monopolist can do is given by the long term contract solution. This is indeed what we obtain, as can be easily verified that:[14]

$$PS^{LT} - PS^{ST} = \frac{\theta_v^{\,2}(g + a\alpha)^2}{4\gamma(g+\alpha)(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]} > 0$$

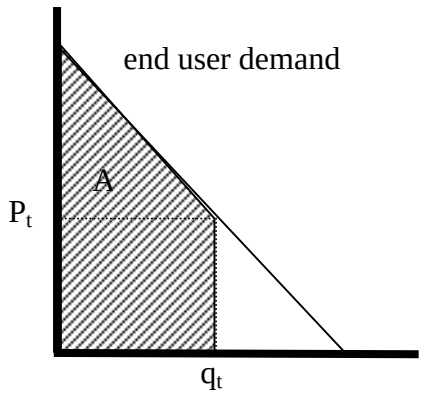
Moreover, as shown in Appendix 1.C, change in social welfare in the context of storage is given by:

$$\Delta SW = (1-\alpha)\Delta\left[CS_v + PS_v^e\right] + \alpha\Delta\left[CS_p + PS_p^e\right] - \Delta StorageSurplus$$

where PS_t^e represents monopolist surplus at time t based on end-user demand. The term ($CS_t + PS_t^e$) is shown as area A in the figure 1.7 below.

[14] We can thus make an argument that in an infinite horizon model, committing to forward sales in the long term contract structure is indeed time consistent for the monopolist. This is so because if the monopolist does not comply with its longer commitment, it risks losing credibility and future higher rents.

Figure 1.7



From the expression above, we note that a decrease in peak and valley prices and a reduction in the usage of storage is a sufficient condition for an increase in social welfare. This is indeed the case of the short term contract structure in relation to the long term contract structure. That is, the social welfare benefits of storage are not only positive under a short term contract structure but more importantly, they are higher than under a long term contract structure[15]. This result holds for all values of peak length, α.

Q.E.D.

This analysis shows that a long term contract structure allows the monopolist pipeline to more effectively limit the competitive effect of storage than a short term contract market structure. This is evidenced by the smaller price differential under a short term contract structure. The competitive effect of storage is so important in a short term contract structure that the drop in peak price is very large in relation to the no storage case. This drop leads to an important increase in peak end-user demand that is only partly offset by storage, and thus leading to an increase in peak throughput.

1.3.2.3. The Equivalent Contract Structure

As in the case with no storage, we need to consider two cases. The first with low levels of seasonality in which the pipeline is better off extracting rents in both the peak

[15] In the presence of storage, the solution to the perfect competitive case is trivial and entails zero peak and valley prices with zero storage injections. In this context, a short term contract structure represents a step closer to the perfectly competitive pipeline sector case than a long term contract structure.

and the valley. The second with high levels of seasonality where the pipeline extracts rents only in the peak.

Case 1: K binding in both peak and valley times

Throughput demand must now incorporate the storage effect. Again, prices are determined such that throughput demand equal K in both valley and peak times:

$$\theta_p - \gamma P_p - \frac{P_p - P_v}{c_s \alpha} = K$$

$$\theta_v - \gamma P_v + \frac{P_p - P_v}{c_s (1-\alpha)} = K$$

Solving this system of equations for P_v and P_p, we have (Appendix 1.D shows the derivation):

$$P_v = \frac{\theta_v (g + a\alpha)}{\gamma (g + \alpha)} - \frac{K}{\gamma}$$

$$P_p = \frac{\theta_v \left[a(g + 2\alpha - 1) + (1-\alpha) \right]}{\gamma (g + \alpha)} - \frac{K}{\gamma}$$

Again, the maximum end users are willing to pay for these rights is $(1-\alpha)P_v + \alpha P_p$. Thus the monopolist problem is:

$$\underset{K}{Max}\, K \left[(1-\alpha) P_v + \alpha P_p \right]$$

Appendix 1.D shows the solution of this problem to be:

$$K^{*EQ} = \frac{\theta_v[a\alpha + (1-\alpha)]}{2}$$

$$P_v^{EQ} = \frac{\theta_v}{2\gamma(g+\alpha)}[g + a\alpha - \alpha(a-1)(g-(1-\alpha))]$$

$$P_p^{EQ} = \frac{\theta_v}{2\gamma(g+\alpha)}[(g+\alpha-2)(a-1) + a(g+\alpha)]$$

$$P_s^{EQ} = \frac{(\theta_p - \theta_v)c_s\alpha(1-\alpha)}{c_s\gamma\alpha(1-\alpha)+1}$$

As in the no storage case, this solution assumes a positive valley price, and thus we require:

$$g + a\alpha - \alpha(a-1)(g-(1-\alpha)) > 0$$

$$\Rightarrow a < \frac{(1-\alpha)(c_s\gamma\alpha(1+\alpha)+1)}{c_s\gamma\alpha(1-\alpha)-1} = a^{1*}$$

Case 2: K binding only in peak times

As in the no storage case, this case holds for a seasonality magnitude greater than the above threshold. Again, valley price is zero and the resulting peak price is

$$P_p = \frac{c_s\alpha(\theta_p - K)}{c_s\gamma\alpha+1}$$

and the resulting monopolist problem becomes:

$$\underset{K}{Max}\, K\frac{c_s\alpha^2(\theta_p - K)}{c_s\gamma\alpha+1}$$

The solution to this problem is thus:

$$K^{*EQ} = \frac{\theta_p}{2}$$

$$P_p^{EQ} = \frac{c_s\alpha\theta_p}{2(c_s\gamma\alpha+1)}$$

$$P_v^{EQ} = 0$$

1.3.2.4. The Welfare Effects of the Equivalent Contract Structure Relative to the Other Structures

Case 1: K binding in both peak and valley times

Figure 1.8 depicts the monopolist solution under the equivalent contract and the long term contract structures. As in the no storage case, we see that valley price under the equivalent contract structure is lower, whereas the peak price is higher. Indeed, it can be easily checked that:

$$\Delta P_v^{LTEQ} = P_v^{LT} - P_v^{EQ} = \frac{\theta_v \alpha (a-1)(g-(1-\alpha))}{2\gamma(g+\alpha)} > 0$$

$$\Delta P_p^{LTEQ} = P_p^{LT} - P_p^{EQ} = -\frac{\theta_v (1-\alpha)(a-1)(g-(1-\alpha))}{2\gamma(g+\alpha)} < 0$$

Similarly,

$$\Delta q_v^{*LTEQ} = q_v^{*LT1} - K^{EQ} = -\frac{\theta_v \alpha (a-1)}{2} < 0$$

$$\Delta q_p^{*LTEQ} = q_p^{*LT1} - K^{EQ} = \frac{\theta_v (1-\alpha)(a-1)}{2} > 0$$

Again, we note that the price and throughput differentials are equal for α=1/2. Furthermore, because the valley price differential is positive and the peak differential is negative, storage usage is larger under the equivalent contract structure.

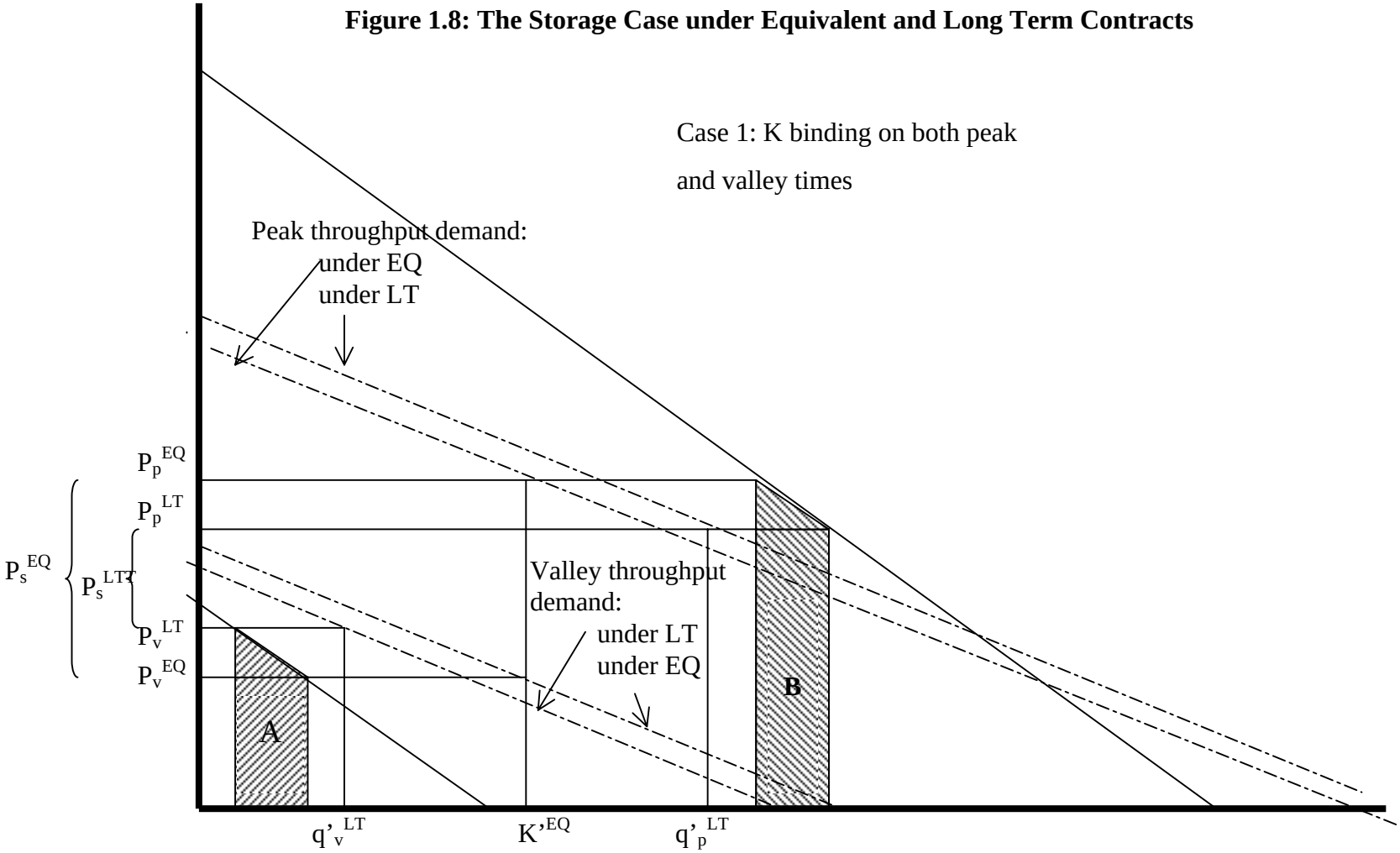
As in the no storage case, we see that valley users are better off and peak end users worse off under the equivalent contract structure. The monopolist, in contrast, is unambiguously worse off because, as argued earlier, cannot do better than with the long term contact structure. Appendix 1.E shows that social welfare under the equivalent contract structure is unambiguously *lower* than under the long term contract structure. Indeed, Appendix 1.E shows that:

$$\Delta\left[CS + PS^e\right]^{LTEQ} = (1-\alpha)\Delta\left[CS_v + PS_v^e\right]^{LTEQ} + \alpha\Delta\left[CS_p + PS_p^e\right]^{LTEQ}$$

$$= \frac{1}{2}(1-\alpha)\gamma\left|\Delta P_v^{LTEQ}\right|\left[P_s^{LT1} + P_s^{EQ}\right] > 0$$

where PS_t^e represents monopolist surplus at time t based on end-user demand. The first bracket term on the RHS of the first line is represented by area A in Figure 1.8, and the second term by area B. As argued earlier, the above condition plus the fact that the long term contract structure leads to a lower storage usage, are sufficient to show it yields

Figure 1.8: The Storage Case under Equivalent and Long Term Contracts



higher social welfare relative to the equivalent contract structure. By transitivity, the equivalent contract structure also leads to a lower social welfare level than the short term contract structure.

Case 2: K binding only in peak times

Figure 1.9 depicts the monopolist solution under the equivalent contract and the short term contract structures. We see that both peak and valley prices are lower under the equivalent contract structure. Indeed, we have:

$$\Delta P_v^{STEQ} = P_v^{ST} - P_v^{EQ} = \frac{2\theta_v c_s (g + a\alpha)}{4c_s\gamma(g+\alpha)+1} > 0$$

$$\Delta P_p^{STEQ} = P_p^{ST} - P_p^{EQ} = \frac{\theta_v c_s (g + a\alpha)}{(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]} > 0$$

We note that the drop in valley price under the equivalent contract structure is larger than the one in peak price. As a result, the storage price is higher under the equivalent contract structure, and consequently, so is storage usage. That is, the equivalent contract structure leads to lower prices albeit a higher storage usage. We cannot thus, make a definite conclusion on the relative social welfare based on these observations. However, Appendix 1.F shows that the equivalent contract structure leads to a higher social welfare than the short term contract structure, and hence a higher social welfare than the long term contract structure. Indeed, Appendix 1.F shows that:

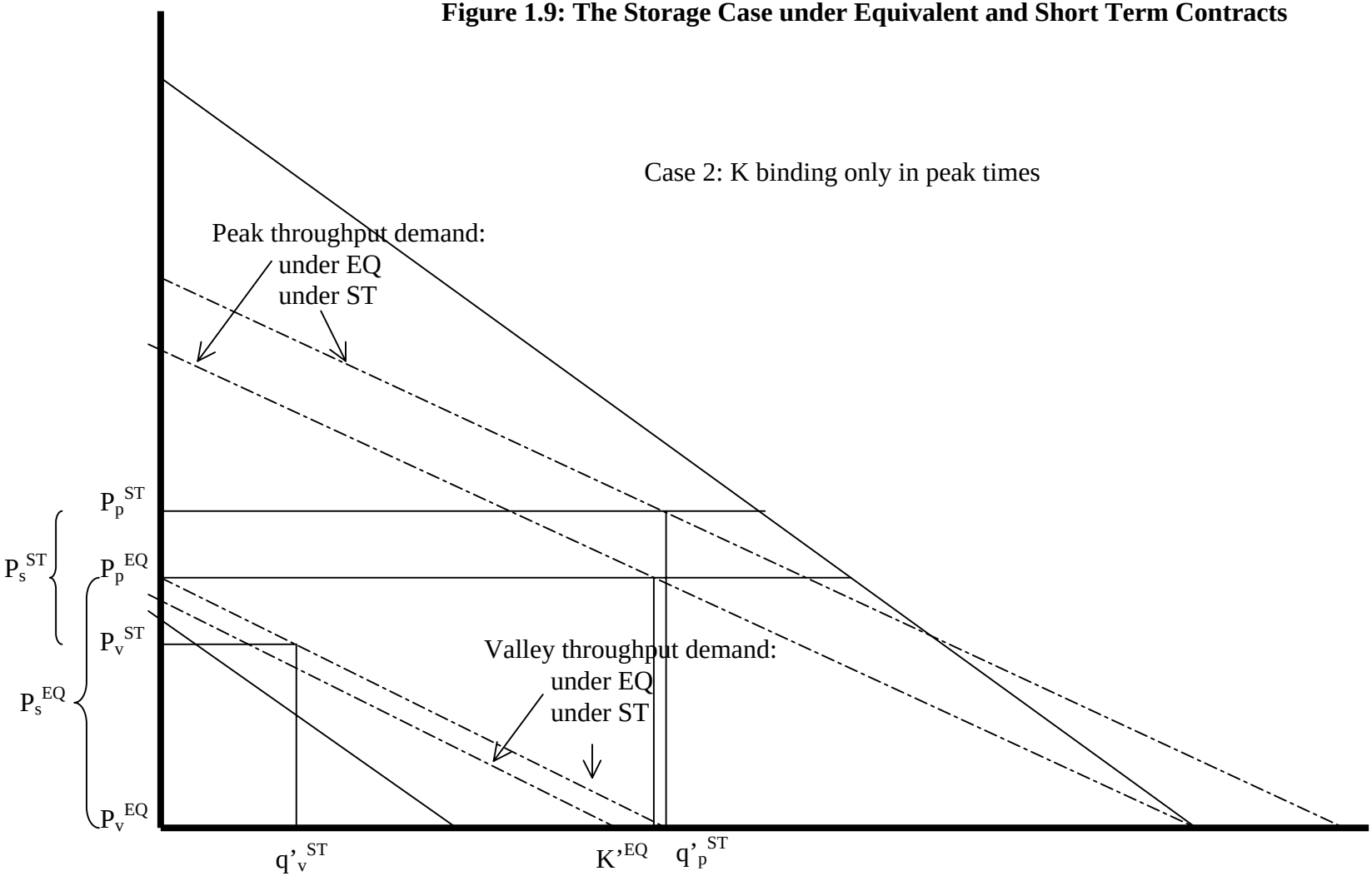
$$\Delta SW^{STEQ} = -\frac{\theta_v^{\,2} c_s (g + a\alpha) g}{2(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]} < 0$$

We can thus summarize our welfare analysis of the equivalent contract structure in the following proposition:

Proposition 1.9

The equivalent contract structure leads to a lower social welfare than either long term or short term contract structures when seasonality is low. In contrast, when seasonality is high, the equivalent contract structure is preferred, from a social welfare point of view, than either the other two contract structures.

Figure 1.9: The Storage Case under Equivalent and Short Term Contracts



1.3.3. Summary

This third section of the chapter analyzed three possible market structures assuming that infrastructure is already in place. The following table summarizes our results with respect to the social benefits of each contract structure:

Table 1.1: Summary of results for Infrastructure in place scenario

	Low seasonality	**High seasonality**
No Storage Case	EQ<LT=ST	LT=ST<EQ
Storage Case	EQ<LT<ST	LT<ST<EQ

From this table, we see that the long term contract structure is never optimal from a social point of view. At best, it yields the same results as the short term contract structure. We note that short term contracts are always better than long term contract in the storage case. As argued before, short term contracts gives less flexibility to the monopolist to counteract the competitive effect of storage. With a short term contract structure, the monopolist has no alternative but to react to the valley price, when determining the peak price. This is in contrast to the long term contract structure which gives it the flexibility to incorporate the effect of valley prices on peak profitability and hence to take into account long term elasticity into its maximization solution. We also see that with low seasonality, the short term contract structure is best. The reason is that with low seasonality, the monopolist tries to obtain some rents in the valley as well and thus, under the equivalent contract structure, will issue an amount of rights between that for peak and that for valley under the long term contract structure. As a result, the increase in welfare in the valley under the equivalent contract structure and relative to the long term contract structure, is more than offset by the loss of welfare in the peak. In contrast, with high seasonality, the equivalent contract is best. It is not optimal for the monopolist to obtain rents in the valley, and thus will let valley price be zero. This, of course, strengthens the competition arising from storage making the peak price to drop so as to limit this competitive effect.

The above analysis has important policy implications. First, it says that giving full flexibility to the monopolist allowing it to make long term contract arrangements is never optimal. Second, it says that the presence of storage can indeed undermine the

monopolistic position of pipelines. Third, it says that the optimal market structure for capacity rights markets depends on the level of seasonality. In the next section of this chapter, we will analyze the investment decision under the same three market structures. We shall see that the distinction between the short term and the long term contract structures is no longer valid. This is so because by determining the investment level at the beginning of the valley, the monopolist is effectively selling forward peak capacity rights. In other words, the investment decision by the monopolist can limit the competitive effect of storage in the case of short term contracts.

1.4. No Infrastructure in Place

This second scenario assumes that no infrastructure is in place. The monopolist pipeline must first decide how big a pipeline to invest and then determine the amount of rights to sell for peak and valley. Under our assumptions of perfect foresight, the monopolist will invest so as to have a capacity constraint in the peak. The following paragraphs will derive the solution for the perfectly competitive pipeline sector and will discuss the three market structures studied above for a monopolist pipeline.

1.4.1. Competitive pipeline sector

In this part, the case of a competitive pipeline sector is analyzed. This case can be thought of as a network of many pipelines delivering gas to a particular consumption center. No single pipeline is big enough to influence capacity prices.

1.4.1.1. Market Equilibrium

The No-Storage Case Equilibrium

The short run marginal cost of delivering gas in this case is 0, when $Q_t<K$, and ∞ for $Q_t>K$, where K represents the capacity of the pipeline. We expect pipeline to be constrained in the peak, and hence the long run marginal cost is k/α, which incorporates the investment cost and the fact that it must be recovered during peak time. That is, peak

end-users pay for the investment costs. The solution to this competitive case is given by the familiar P=MC principle.

The solution in the peak period is thus given by:

$$\frac{\theta_p - q'_p}{\gamma} = \frac{k}{\alpha}$$

and thus, we have:

$$q_p' = \theta_p - \frac{\gamma k}{\alpha}$$

$$P_p = \frac{k}{\alpha}$$

The solution in the valley period is given by:

$$\frac{\theta_v - q'_v}{\gamma} = 0$$

and thus, we have[16]:

$$q'_v = \theta_v$$

$$P_v = 0$$

The Storage Case Equilibrium

We still have peak end users paying for investment costs. The P=MC principle leads to the peak period solution given by:

$$\frac{\theta_p c_s \alpha + P_v - q'_p c_s \alpha}{c_s \alpha \gamma + 1} = \frac{k}{\alpha}$$

and the valley period solution given by:

$$\frac{\theta_v c_s (1-\alpha) + P_p - q'_v c_s (1-\alpha)}{c_s \gamma (1-\alpha) + 1} = 0$$

The solution to these simultaneous equations is given by:

---

[16] Seasonality is assumed to be sufficiently large to guarantee an interior solution, so peak throughput is greater than valley throughput. That is, $a>1+k\gamma/(\alpha\theta_v)$ is assumed.

$$q'_v = \theta_v + \frac{k}{c_s(1-\alpha)\alpha}$$

$$P_v = 0$$

$$q'_p = \theta_v - \gamma\frac{k}{\alpha} - \frac{k}{c_s\alpha}$$

$$P_p = \frac{k}{\alpha}$$

The resulting gas amount put in storage is:

$$Q_s = \frac{P_s}{c_s} = \frac{k}{c_s\alpha}$$

Note that as the peak length, α, the valley price decreases. The reason is that as α increases there is more time to recover investment costs, and thus less need to charge for the recovery of these costs.

1.4.1.2. The Welfare Effects of Storage

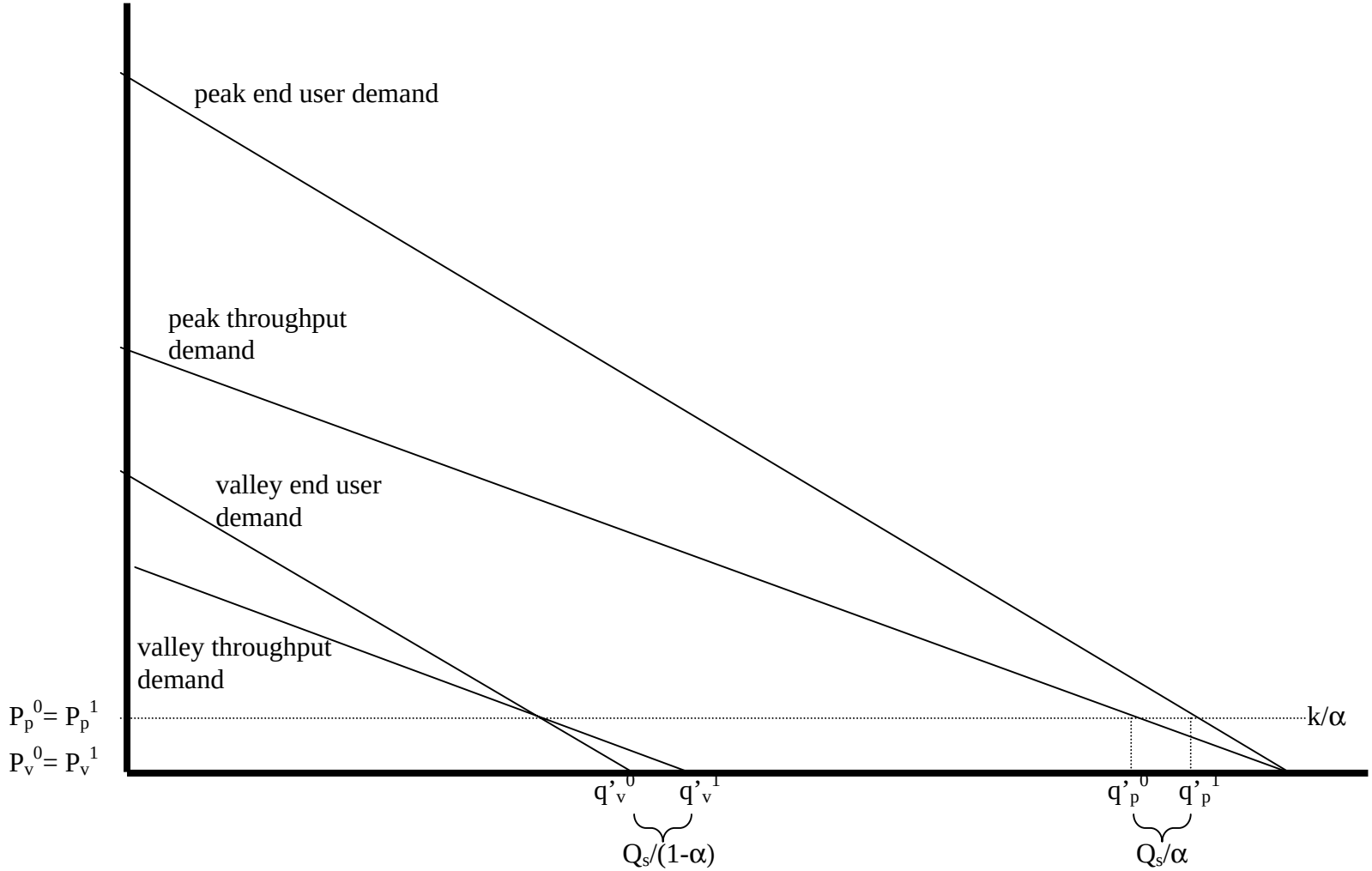
Figure 1.10 shows this competitive pipeline sector for the no storage and storage cases. The first thing to notice is that storage does not affect equilibrium prices in both periods [17]. End user consumption remains unchanged in both periods. The difference between the two cases lies on how the gas is delivered. Storage leads to an increase in throughput in the valley period and a decrease in throughput in the peak period. That is, there is a decrease in the amount of pipeline that remains idle in the valley period. There is a better utilization of capital, as the same amount of gas is being delivered with a lower investment level. This better utilization of capital leads to an increase in social welfare. Indeed, from our result of Appendix 1.C and incorporating investment costs, we have:

$$\Delta SW^C = SW^1 - SW^0 = \Delta[CS + PS]^C - \Delta StorageSurplus^C + \Delta InvestmentCost^C$$

Since the price remain unchanged, the first bracket term is 0. The other two terms lead to:

[17] A model with increasing marginal costs in the operation of pipelines would lead to a reduction in peak price and an increase in valley price, associated with the decrease in peak throughput and the increase in valley throughput.

Figure 1.10: Investments under the Competitive Case



$$\Delta SW^C = \frac{k^2}{2c_s\alpha} > 0$$

We see that investment costs has three effects[18]. First, peak prices increase by a factor necessary for the recovery of investment costs which decreases peak throughput. Second, this factor leads to a larger difference between peak and valley prices and hence to larger storage usage. And third, this larger storage usage leads to higher valley throughput and further decreases peak throughput. We will see these three effects in our analysis of the three contract structures.

1.4.2. The Equivalency of Long Term and Short Term Contract Structures

The second part of the chapter analyzing the scenario where infrastructure is already in place showed that the long term and short term contract structures are equivalent in the case of no storage. However, in the case of storage, short term contracts lead to higher social benefits. In contrast, when analyzing the investment decision, long term and short term contracts are equivalent in *both* storage and no storage cases. Indeed, the investment decision by the pipeline in the short term contract structure effectively sells capacity rights forward.

1.4.2.1. The No Storage Market Equilibrium

Again, there is no linkage between the market in the peak and in the valley. Thus the short term and long term contract structures lead to the same equilibrium outcome. We introduce investment decision into our previous analysis in the scenario with infrastructure in place. Capacity will be binding in the peak. Thus, the monopolist problem is:

$$\underset{P_v, P_p}{Max}(1-\alpha)(\theta_v - \gamma P_v)P_v + \alpha(\theta_p - \gamma P_p)P_p - k(\theta_p - \gamma P)$$

[18] The solution of the competitive pipeline sector with no investment decision is trivial as it yields to zero prices and no storage usage.

The solution to this problem is given by:

$$P_v^{LT} = \frac{\theta_v}{2\gamma}$$
$$q_v^{LT} = \frac{\theta_v}{2}$$

The peak solution is given by:

$$P_p^{LT} = \frac{\theta_p}{2\gamma} + \frac{k}{2\alpha}$$
$$q_p^{LT} = \frac{\theta_p}{2} - \frac{k\gamma}{2\alpha}$$

To insure that peak capacity is binding only in the peak, we assume[19]:

$$a > 1 + \frac{k\gamma}{\theta_v \alpha}$$

1.4.2.2. The Storage Market Equilibrium

The Long Term Contract Structure

Introducing investment decision into our previous analysis leads to the following monopolist problem:

$$\underset{P_v, P_p}{Max}(1-\alpha)P_v\left[\theta_v - \gamma P_v + \frac{Q_s(P_p, P_v)}{(1-\alpha)}\right] + (\alpha P_p - k)\left[\theta_p - \gamma P_p - \frac{Q_s(P_p, P_v)}{\alpha}\right]$$

and the resulting FOCs for P_v and P_p are, respectively:

[19] The case where capacity is binding in the both periods is not very interesting from an economic point of view, and thus is neglected.

$$\left[(1-\alpha)(\theta_v - 2\gamma P_v)\right] + \left(\frac{\partial Q_s}{\partial P_v} P_v + Q_s\right) - \left[\frac{\partial Q_s}{\partial P_v} P_p\right] + \left[\frac{k}{\alpha}\frac{\partial Q_s}{\partial P_v}\right] = 0$$

$$\left[\alpha\left(\theta_p - 2\gamma P_v\right)\right] - \left[\frac{\partial Q_s}{\partial P_p} P_p + Q_s\right] + \left[\frac{\partial Q_s}{\partial P_p} P_v\right] + \left[k\left(\frac{1}{\alpha}\frac{\partial Q_s}{\partial P_p} + \gamma\right)\right] = 0$$

These FOCs show the three effects identified earlier plus an additional fourth effect shown in the last bracket term of each equation. This term shows the effect of prices on the investment cost. This effect has only one component in the FOC for the valley price: as higher valley price leads to lower storage usage and hence a higher peak throughput and investment level, *ceteris paribus*. In contrast, the first component says that a higher peak price leads to a greater usage of storage and hence a lower investment level. The second component relates to the notion that investment is paid by peak end-users.

Appendix 1.G shows the derivation of the solution to these FOCs, which is given by:

$$P_v^{LT} = \frac{\theta_v(g + a\alpha)}{2\gamma(g+\alpha)}$$

$$P_p^{LT} = \frac{\theta_v}{2\gamma(g+\alpha)}\left[(1-\alpha)c_s\gamma\alpha(a-1) + g + a\alpha\right] + \frac{k}{2\alpha}$$

$$q_v^{LT} = \frac{\theta_v}{2} + \frac{k}{2c_s\alpha(1-\alpha)} > q_v^{LT0}$$

$$q_p^{LT} = \frac{\theta_p}{2} - \frac{k}{2\alpha}\left(\gamma + \frac{1}{c_s\alpha}\right) < q_p^{LT0}$$

The superscript o denotes the equilibrium in the no storage case. The resulting gas amount injected into storage is:

$$Q_s^{LT} = \frac{P_s^{LT}}{c_s} = \frac{\theta_v\alpha(1-\alpha)(a-1)}{2(g+\alpha)} + \frac{k}{2\alpha c_s} > 0$$

In this analysis we assume that capacity is binding in the peak and hence[20],

$$a > 1 + \frac{k}{c_s \alpha \theta_v} \frac{g+\alpha}{\alpha(1-\alpha)}$$

It is interesting to compare this result with the one obtained when assuming the infrastructure was already in place. Unlike to the first scenario, storage here leads to an increase in valley throughput and a decrease in peak throughput relative to the no storage case. This is driven by the fact that investment is paid by peak end users, and thus the extra term containing k in the peak price. This extra term creates an extra incentive for storage usage not present when we assumed the infrastructure to be in place. This extra incentive for storage usage increases valley throughput and decreases peak throughput.

Figure 1.11 shows depicts the no storage and the storage cases for α=1/2 and a long term market structure. As noted above, storage leads to an increase in valley throughput demand and a decrease in peak throughput demand. Also, as in the previous analysis, the presence of storage leads to an increase in valley price and a decrease in peak price, as expected. The magnitude of these price changes is given by:

$$\Delta P_v^{LT} = P_v^{LT} - P_v^{LT0} = \frac{\theta_v \alpha (a-1)}{2\gamma(g+\alpha)} > 0$$

$$\Delta P_p^{LT} = P_p^{LT} - P_p^{LT0} = \frac{-\theta_v (1-\alpha)(a-1)}{2\gamma(g+\alpha)} < 0$$

Again, the superscript o denotes the equilibrium with no storage. Note that these price differentials are the same as those obtained in the previous analysis assuming infrastructure was already in place.

The Short Term Contract Structure

The solution to the short term contract structure is derived through backward induction.

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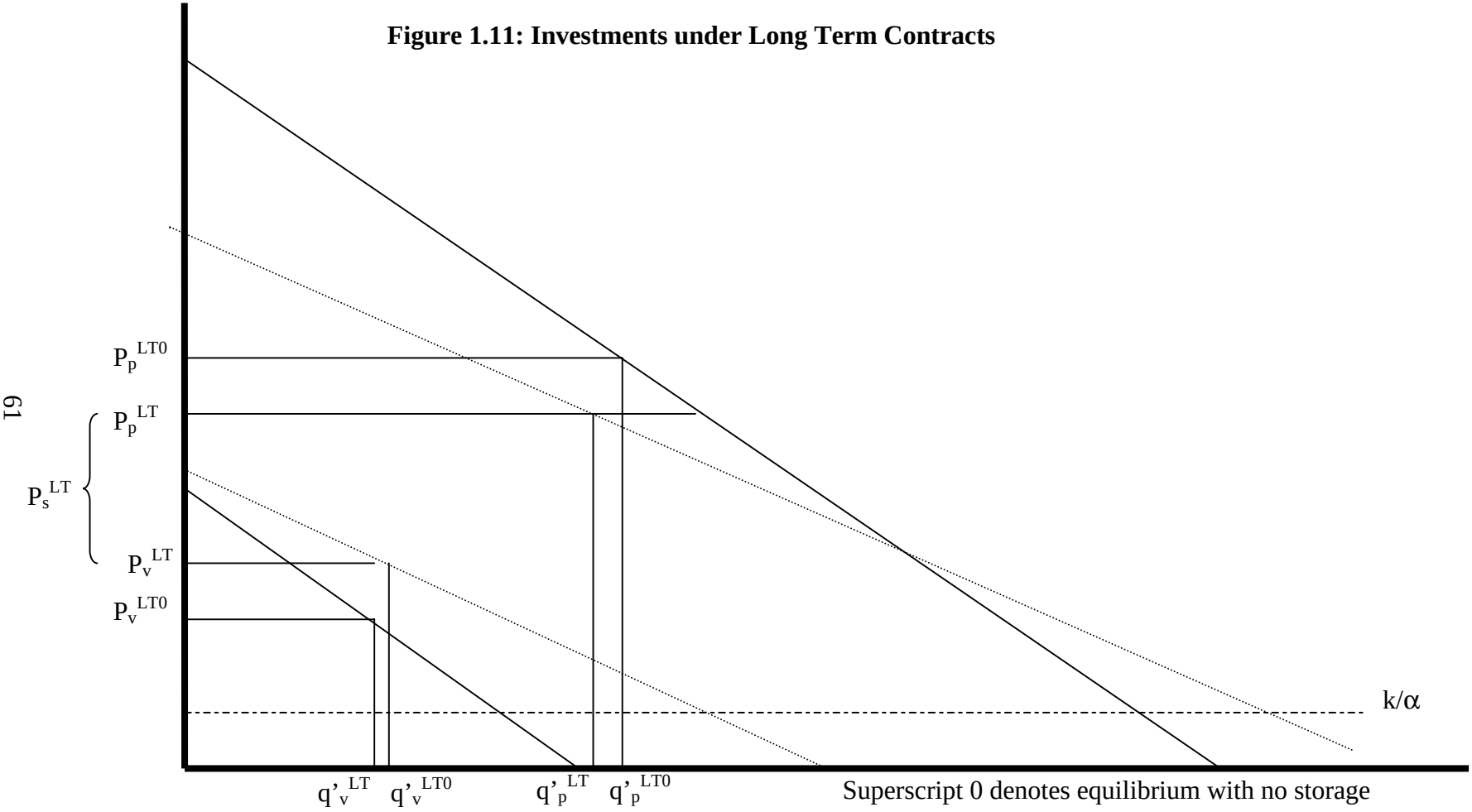
[20] As in our previous analysis, our expression for valley throughput demand also assumes a positive valley end-user demand. Thus, we assume the resulting $P_v^{LT1} < \theta_v/\gamma$ or $a < 2 + g/\alpha$.

Figure 1.11: Investments under Long Term Contracts



The peak period problem

The pipeline when solving its peak period problem takes the capacity K and valley price as given. As argued earlier, the investment decision will be such that capacity binds in the peak. Hence:

$$K = \theta_p - \gamma P_p - \frac{P_p - P_v}{c_s \alpha}$$

and the resulting peak price and peak profitability are given by:

$$P_p = \frac{1}{c_s \gamma \alpha + 1}\left[c_s \alpha(\theta_p - K) + P_v\right]$$

$$\Pi_p = \frac{\alpha K}{c_s \gamma \alpha + 1}\left[c_s \alpha(\theta_p - K) + P_v\right]$$

The valley period problem

In the valley, the monopolist wants to maximize overall profit less investment costs. That is, the problem is:

$$\underset{P_v, K}{Max}(1-\alpha)\left[\theta_v - \gamma P_v + \frac{Q_s(P_p(P_v, K), P_v)}{1-\alpha}\right]P_v + \prod_p(P_p(P_v, K), P_v) - kK$$

Substituting and rearranging terms leads to the following FOCs:

$$\theta_v(g + a\alpha) - 2\gamma P_v(g + \alpha) = 0$$

$$\frac{\theta_p}{c_s \gamma \alpha + 1} - \frac{k}{c_s \alpha^2} - \frac{2K}{c_s \gamma \alpha + 1} = 0$$

which lead to the following equilibrium conditions:

$$P_v^{ST} = \frac{\theta_v(g + a\alpha)}{2\gamma(g + \alpha)}$$

$$K_v^{ST} = \frac{\theta_p}{2} - \frac{k}{2\alpha}(\gamma + \frac{1}{c_s \alpha})$$

Note that these conditions are exactly the same as the corresponding conditions for the long term contract structure. That is, the two structures yield identical results. This would suggest that the monopolist does no longer react to valley prices in the peak, as we concluded in the scenario with infrastructure in place. By making the investment

decision simultaneous to the valley price, the monopolist is effectively selling forward capacity rights for the peak, since capacity will be binding in the peak. Thus, making the investment decision allows it to incorporate long term demand elasticity into the monopolist valley problem. What was so attractive about this contract structure when infrastructure is in place is lost here. A short term contract structure no longer limits the ability of the monopolist to fend off the competitive effect of storage. The following proposition summarizes this result.

Proposition 1.10

Through the investment decision, a monopolist pipeline effectively sells capacity forward through the investment decision in the context of a short term contract structure. As such, the long term and short term contract structures are equivalent in both storage and no storage cases.

1.4.3. Summary

The investment decision does not change the value, from a social point of view, of the equivalent contract structure relative to either long term or short term contract structures. Mathematically, there is an extra component related to the investment cost in the solutions derived in the second part of the chapter. The investment decision does not change the problem the monopolist faces under an equivalent contract structure as it does under a short term contract structure. Hence, the equivalent contract structure leads to higher social welfare with high seasonalities and lower social welfare with low seasonalities. The following table summarizes this:

Table 1.2: Summary of results for No Infrastructure in place scenario

	Low seasonality	**High seasonality**
No Storage Case	EQ<LT=ST	LT=ST<EQ
Storage Case	EQ<LT=ST	LT=ST<EQ

Comparing to Table 1.1, this table shows that in all four cases, short term and long term contract structures are equivalent. This is not true when infrastructure is already in place. However, the relative value of the equivalent contract structure is the same in both scenarios.

1.5. Conclusions

The main insight presented in this model is that the competitive effect of storage depends on the capacity rights market structure. This implies that policy makers have to be very careful in designing the structure of capacity rights markets. While the pipeline sector in many regions in the United States is competitive, there are regions where there are few pipelines competing for the delivery of gas. The structure of capacity rights markets will have an important bearing on these regions. Furthermore, the model shows that the current structure of the capacity rights market in the United States, characterized by the equivalent contract structure in this analysis, might not be optimal in regions with low seasonalities. In such regions, a short term contract structure would enhance social welfare. The chapter also has important implications for infant natural markets where the pipeline infrastructure is very much underdeveloped and hence there is little competition in the pipeline sector. The model shows that there is no distinction what so ever between a short term and a long term contract structure when the monopolist pipeline must also decide on the investment level. In such markets, the monopolist pipeline has greater ability to limit the competitive effect of storage. In any case however, infant markets should aim at encouraging investments in storage facilities as these tend to introduce competition to the monopolist pipeline and increase social welfare.

The next chapter introduces extends the analysis presented here by introducing uncertainty. Uncertainty breaks down the equivalency between short term and long term contract structures, and as such has important implications in the ability of the pipeline to fend off the competitive effect of storage. Moreover, although long term contracts might strengthen the competitive effect of storage, it has the benefit of allocating risks in a more efficient manner, as discussed in the third chapter. It is important that regulators take all these elements into consideration when designing capacity rights markets both in the United States and abroad.

Appendix 1.A: Derivation of solution under long term contract structure and infrastructure already in place

Here we derive the market equilibrium in the presence of storage. The problem facing the monopolist pipeline is given by:

$$\underset{P_v,P_p}{Max}(1-\alpha)P_v\left[\theta_v-\gamma P_v+\frac{P_p-P_v}{c_s(1-\alpha)}\right]+\alpha P_p\left[\theta_p-\gamma P_p-\frac{P_p-P_v}{c_s\alpha}\right]$$

The resulting First Order Conditions (FOC) are given by:

$$\theta_v c_s(1-\alpha)+2P_p-2P_v\left(c_s\gamma(1-\alpha)+1\right)=0$$
$$\theta_v a c_s\alpha+2P_v-2P_p\left(c_s\gamma\alpha+1\right)=0$$

From the first equation, we have:

$$2P_p=2P_v\left(c_s\gamma(1-\alpha)+1\right)-\theta_v c_s(1-\alpha)$$

and into the second equation leads to:

$$P_v^{LT}=\frac{\theta_v\left((1-\alpha)(c_s\gamma\alpha+1)+a\alpha\right)}{2\gamma\left(c_s\gamma\alpha(1-\alpha)+1\right)}$$
$$=\frac{\theta_v\left(g+a\alpha\right)}{2\gamma\left(g+\alpha\right)}$$

where g=(1-α)(c_sγα+1). Thus, we have:

$$P_p^{LT}=\frac{\theta_v\left[(1-\alpha)+a\alpha\left(c_s\gamma(1-\alpha)+1\right)\right]}{2\gamma\left(c_s\gamma\alpha(1-\alpha)+1\right)}$$
$$=\frac{\theta_v\left[g-(1-\alpha)c_s\gamma\alpha+a\alpha\left(c_s\gamma(1-\alpha)+1\right)\right]}{2\gamma\left(g+\alpha\right)}$$
$$=\frac{\theta_v\left(g+a\alpha+(1-\alpha)c_s\gamma\alpha(a-1)\right)}{2\gamma\left(g+\alpha\right)}$$

Similarly, we get:

$$Q_s^{LT}=\frac{P_p-P_v}{c_s}$$
$$=\frac{\theta_v(1-\alpha)\alpha(a-1)}{2\left(g+\alpha\right)}$$

and

$$q_p^{*LT} = \theta_p - \frac{\theta_v \gamma \left(g + a\alpha + (1-\alpha)c_s \gamma \alpha (a-1)\right)}{2\gamma(g+\alpha)} - \frac{\theta_v (1-\alpha)\alpha(a-1)}{2(g+\alpha)\alpha}$$
$$= \frac{\theta_v \left(2a(g+\alpha) - g - a\alpha - (a-1)g\right)}{2(g+\alpha)}$$
$$= \frac{\theta_p}{2}$$

Also,

$$q_v^{*LT} = \theta_v - \frac{\theta_v \gamma \left(g + a\alpha\right)}{2\gamma(g+\alpha)} + \frac{\theta_v (1-\alpha)\alpha(a-1)}{2(g+\alpha)(1-\alpha)}$$
$$= \frac{\theta_v \left(2(g+\alpha) - g - \alpha\right)}{2(g+\alpha)}$$
$$= \frac{\theta_v}{2}$$

Appendix 1.B: Derivation of solution under short term contract structure and infrastructure already in place

Here we derive the market equilibrium in the presence of storage. The solution is derived via backward induction.

Peak Period Problem

The monopolist takes valley price as given and the problem it faces is given by:

$$\underset{P_v}{Max}\, \alpha P_p \left[\theta_p - \gamma P_p - \frac{P_p - P_v}{c_s \alpha} \right]$$

The resulting First Order Condition (FOC) is given by:

$$\theta_p c_s \alpha + P_v - 2P_v \left(c_s \gamma \alpha + 1\right) = 0$$

Hence we have:

$$P_p = \frac{\theta_p \alpha c_s + P_v}{2(c_s \gamma \alpha + 1)}$$

and

$$q'_p = \theta_p + \frac{P_v}{c_s\alpha} - \frac{(\theta_p\alpha c_s + P_v)(c_s\gamma\alpha+1)}{2(c_s\gamma\alpha+1)c_s\alpha}$$
$$= \frac{\theta_p\alpha c_s + P_v}{2c_s\alpha}$$

This leads to a profit level for the peak equal to

$$\Pi_p = \frac{[\theta_p\alpha c_s + P_v]^2}{4c_s(c_s\gamma\alpha+1)}$$

Valley Period Problem

In the valley, the monopolist pipeline faces the following problem (taking the solution of the peak period into account):

$$\underset{P_v}{Max}(1-\alpha)\left[\theta_v - \gamma P_v + \frac{P_p(P_v) - P_v}{c_s(1-\alpha)}\right]P_v + \Pi_p(P_v)$$
$$\Leftrightarrow \underset{P_v}{Max}\left[(1-\alpha)(\theta_v - \gamma P_v) + \frac{\theta_p c_s\alpha - P_v(2c_s\gamma\alpha+1)}{2c_s(c_s\gamma\alpha+1)}\right]P_v + \frac{[\theta_p\alpha c_s + P_v]^2}{4c_s(c_s\gamma\alpha+1)}$$
$$\Leftrightarrow \underset{P_v}{Max}\left[\frac{\theta_v c_s[2(1-\alpha)(c_s\gamma\alpha+1) + a\alpha] - P_v[2c_s\gamma(1-\alpha)(c_s\gamma\alpha+1) + (2c_s\gamma\alpha+1)]}{2c_s(c_s\gamma\alpha+1)}\right]P_v + \frac{[\theta_p\alpha c_s + P_v]^2}{4c_s(c_s\gamma\alpha+1)}$$

The resulting First Order Condition (FOC) is given by:

$$2\theta_v c_s[(1-\alpha)(c_s\gamma\alpha+1) + a\alpha] - P_v[4c_s\gamma((1-\alpha)(c_s\gamma\alpha+1) + \alpha) + 1] = 0$$

and hence, we have:

$$P_v^{ST} = \frac{2\theta_v c_s[(1-\alpha)(c_s\gamma\alpha+1) + a\alpha]}{4c_s\gamma((1-\alpha)(c_s\gamma\alpha+1) + \alpha) + 1}$$
$$= \frac{2\theta_v c_s(g + a\alpha)}{4c_s\gamma(g+\alpha) + 1}$$

where $g=(1-\alpha)(c_s\gamma\alpha+1)$. Plugging into our peak solution yields to:

$$P_p^{ST} = \frac{\theta_p\alpha c_s}{2(c_s\gamma\alpha+1)} + \frac{2\theta_v c_s(g+a\alpha)}{2(c_s\gamma\alpha+1)(4c_s\gamma(g+\alpha)+1)}$$
$$= \frac{\theta_v c_s[a\alpha(4c_s\gamma(g+\alpha)+3) + 2g]}{2(c_s\gamma\alpha+1)[4c_s\gamma(g+\alpha)+1]}$$

The resulting amount put in storage is given by:

$$
\begin{aligned}
Q_s^{ST} &= \frac{P_p - P_v}{c_s} \\
&= \frac{\theta_v\left[a\alpha\left(4c_s\gamma(g+\alpha)+3\right)+2g\right]}{2(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]} - \frac{4\theta_v\left(g+a\alpha\right)(c_s\gamma\alpha+1)}{2(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]} \\
&= \frac{\theta_v\left[a\alpha\left(4c_s\gamma g-1\right)-2g\left(2c_s\gamma\alpha+1\right)\right]}{2(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]}
\end{aligned}
$$

The resulting throughput amounts are given by:

$$
\begin{aligned}
q_v^{ST} &= \theta_v - \frac{2\theta_v c_s\gamma\left(g+a\alpha\right)}{4c_s\gamma(g+\alpha)+1} + \frac{\theta_v\left[a\alpha\left(4c_s\gamma g-1\right)-2g\left(2c_s\gamma\alpha+1\right)\right]}{2(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right](1-\alpha)} \\
&= \frac{\theta_v}{2} + \frac{\theta_v g\left[4c_s\gamma(g+\alpha)+1\right]}{2g\left[4c_s\gamma(g+\alpha)+1\right]} - \frac{4\theta_v c_s\gamma g\left(g+a\alpha\right)}{2g\left[4c_s\gamma(g+\alpha)+1\right]} + \frac{\theta_v\left[a\alpha\left(4c_s\gamma g-1\right)-2g\left(2c_s\gamma\alpha+1\right)\right]}{2g\left[4c_s\gamma(g+\alpha)+1\right]} \\
&= \frac{\theta_v}{2}\left[1 - \frac{g+a\alpha}{2g\left(4c_s\gamma(g+\alpha)+1\right)}\right]
\end{aligned}
$$

and

$$
\begin{aligned}
q_p^{ST} &= \theta_p - \frac{\theta_v c_s\gamma\left[a\alpha\left(4c_s\gamma(g+\alpha)+3\right)+2g\right]}{2(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]} - \frac{\theta_v\left[a\alpha\left(4c_s\gamma g-1\right)-2g\left(2c_s\gamma\alpha+1\right)\right]}{2\alpha(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]} \\
&= \frac{\theta_p}{2} + \frac{\theta_v a\alpha(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]}{2\alpha(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]} - \frac{\theta_v c_s\gamma\alpha\left[a\alpha\left(4c_s\gamma(g+\alpha)+3\right)+2g\right]}{2\alpha(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]} \\
&\quad - \frac{\theta_v\left[a\alpha\left(4c_s\gamma g-1\right)-2g\left(2c_s\gamma\alpha+1\right)\right]}{2\alpha(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]} \\
&= \frac{\theta_v}{2}\left[a - \frac{g+a\alpha}{\alpha\left(4c_s\gamma(g+\alpha)+1\right)}\right]
\end{aligned}
$$

Appendix 1.C: Derivation for the expression for Social Welfare in the presence of storage

Social welfare is given by the sum of consumer surplus, pipeline surplus and storage surplus:

$$
\begin{aligned}
SW &= (1-\alpha)\left[CS_v + PS_v\right] + \alpha\left[CS_p + PS_p\right] + StorageSurplus \\
&= (1-\alpha)\left[\frac{1}{2}\left(\frac{\theta_v}{\gamma} - P_v\right)q_v + \left(q_v + \frac{P_p - P_v}{c_s(1-\alpha)}\right)P_v\right] + \alpha\left[\frac{1}{2}\left(\frac{\theta_p}{\gamma} - P_p\right)q_p + \left(q_p - \frac{P_p - P_v}{c_s\alpha}\right)P_p\right] \\
&\quad + \frac{1}{2}\frac{\left(P_p - P_v\right)^2}{c_s} \\
&= (1-\alpha)\left[\frac{1}{2}\left(\frac{\theta_v}{\gamma} - P_v\right)q_v + q_v P_v\right] + \alpha\left[\frac{1}{2}\left(\frac{\theta_p}{\gamma} - P_p\right)q_p + q_p P_p\right] - \frac{1}{2}\frac{\left(P_p - P_v\right)^2}{c_s} \\
&= (1-\alpha)\left[CS_v + PS_v^e\right] + \alpha\left[CS_p + PS_p^e\right] - StorageSurplus
\end{aligned}
$$

where PS_t^e represents producer surplus at time t based on end-user demand, as illustrated in figure 1.7 in the text.

Appendix 1.D: Derivation of the solution to the monopolist problem under the equivalent contract structure in the presence of storage and K binding both in valley and peak times

Prices are determined such that throughput demand equal K in both valley and peak times:

$$\theta_p - \gamma P_p - \frac{P_p - P_v}{c_s\alpha} = K$$

$$\theta_v - \gamma P_v + \frac{P_p - P_v}{c_s(1-\alpha)} = K$$

Equating these two equations yields to

$$P_p = \frac{(\theta_p - \theta_v)c_s\alpha(1-\alpha)}{c_s\gamma\alpha(1-\alpha)+1} + P_v$$

and plugging into the first equation leads to:

$$P_v = \frac{\theta_v(g + a\alpha)}{\gamma(g+\alpha)} - \frac{K}{\gamma}$$

Thus, we have:

$$P_p = \frac{\theta_v\left[a(g + 2\alpha - 1) + (1-\alpha)\right]}{\gamma(g+\alpha)} - \frac{K}{\gamma}$$

The maximum end-users are willing to pay for these rights is:

$$(1-\alpha)P_v + \alpha P_p = \frac{\theta_v}{\gamma(g+\alpha)}\left[(g+a\alpha)(1-\alpha) + a\alpha(g+2\alpha-1) + (1-\alpha\alpha)\right] - \frac{K}{\gamma}$$
$$= \frac{\theta_v\left[a\alpha + (1-\alpha)\right]}{\gamma} - \frac{K}{\gamma}$$

Thus, the monopolist problem becomes:

$$\underset{K}{Max}\, K\left[\frac{\theta_v\left[a\alpha + (1-\alpha)\right]}{\gamma} - \frac{K}{\gamma}\right]$$

The solution to this problem is:

$$K^{EQ} = \frac{\theta_v\left[a\alpha + (1-\alpha)\right]}{2}$$

Thus we obtain,

$$P_v^{EQ} = \frac{\theta_v(g+a\alpha)}{\gamma(g+\alpha)} - \frac{\theta_v\left[a\alpha + (1-\alpha)\right]}{2\gamma}$$
$$= \frac{\theta_v(g+a\alpha)}{2\gamma(g+\alpha)} + \frac{\theta_v(g+a\alpha)}{2\gamma(g+\alpha)} - \frac{\theta_v(g+\alpha)\left[a\alpha + (1-\alpha)\right]}{2\gamma(g+\alpha)}$$
$$= \frac{\theta_v}{2\gamma(g+\alpha)}\left[g + a\alpha - \alpha(a-1)(g-(1-\alpha))\right]$$

Similarly, we have

$$P_p^{EQ} = \frac{\theta_v\left[a(g+2\alpha-1) + (1-\alpha)\right]}{\gamma(g+\alpha)} - \frac{\theta_v\left[a\alpha + (1-\alpha)\right]}{2\gamma}$$
$$= \frac{\theta_v}{2\gamma(g+\alpha)}\left[2a(g+2\alpha-1) + 2(1-\alpha) - (g+\alpha)(a\alpha + (1-\alpha))\right]$$
$$= \frac{\theta_v}{2\gamma(g+\alpha)}\left[(g+\alpha)(a-1) - 2(1-\alpha)(a-1) + (g+\alpha)(a(1-\alpha)+\alpha)\right]$$
$$= \frac{\theta_v}{2\gamma(g+\alpha)}\left[(g+\alpha-2)(a-1) + a(g+\alpha)\right]$$

And the resulting storage price is

$$P_s^{EQ} = \frac{(\theta_p - \theta_v)c_s\alpha(1-\alpha)}{c_s\gamma\alpha(1-\alpha)+1}$$

Appendix 1.E: Proof that the equivalent contract structure leads to a lower social welfare than the long term contract structure for low seasonality and storage

From Appendix 1.C, we know that social welfare in the presence of storage is given by:

$$SW = (1-\alpha)\left[CS_v + PS_v^e\right] + \alpha\left[CS_p + PS_p^e\right] - StorageSurplus$$

where PS_t^e represents producer surplus at time t based on end-user demand.

From Figure 1.8, we have:

$$\begin{aligned}\Delta\left[CS + PS^e\right]^{LTEQ} &= (1-\alpha)\Delta\left[CS_v + PS_v^e\right]^{LTEQ} + \alpha\Delta\left[CS_p + PS_p^e\right]^{LTEQ} \\ &= -(1-\alpha)\left|\Delta q_v^{LTEQ}\right|\left[\frac{1}{2}\Delta P_v^{LTEQ} + P_v^{EQ}\right] + \alpha\Delta q_p^{LTEQ}\left[\frac{1}{2}\left|\Delta P_p^{LTEQ}\right| + P_p^{LT}\right]\end{aligned}$$

where Δq_t^{LTEQ} represents the change in end user demand. We note that

$$\Delta q_t^{LTEQ} = -\gamma\Delta P_t^{LTEQ}$$

Also, it can be checked that:

$$(1-\alpha)\left|\Delta P_v^{LTEQ}\right| = \alpha\left|\Delta P_p^{LTEQ}\right|$$

Hence, we have

$$\begin{aligned}\Delta\left[CS + PS^e\right]^{LTEQ} &= (1-\alpha)\gamma\Delta P_v^{LTEQ}\left[-\frac{1}{2}\Delta P_v^{LTEQ} - P_v^{EQ} + \frac{1}{2}\left|\Delta P_p^{LTEQ}\right| + P_p^{LT}\right] \\ &= (1-\alpha)\gamma\Delta P_v^{LTEQ}\left[-\frac{1}{2}\left[P_v^{LT} - P_v^{EQ} + P_p^{LT} - P_p^{EQ}\right] - P_v^{EQ} + P_p^{LT}\right] \\ &= \frac{1}{2}(1-\alpha)\gamma\Delta P_v^{LTEQ}\left[P_p^{EQ} - P_v^{EQ} + P_p^{LT} - P_v^{LT}\right] \\ &= \frac{1}{2}(1-\alpha)\gamma\Delta P_v^{LTEQ}\left[P_s^{EQ} + P_s^{LT}\right] > 0\end{aligned}$$

Appendix 1.F: Proof that the equivalent contract structure leads to a higher social welfare than the short term contract structure for high seasonality and storage

From Appendix 1.C, we know that social welfare in the presence of storage is given by:

$$SW = (1-\alpha)\left[CS_v + PS_v^e\right] + \alpha\left[CS_p + PS_p^e\right] - StorageSurplus$$

where PS_t^e represents producer surplus at time t based on end-user demand.

From Figure 1.9 in the text, we have:

$$\Delta\left[CS + PS^e\right]^{STEQ} = -(1-\alpha)\Delta\left[CS_v + PS_v^e\right]^{STEQ} - \alpha\Delta\left[CS_p + PS_p^e\right]^{STEQ}$$
$$= -(1-\alpha)\left|\Delta q_v^{STEQ}\right|\left[\frac{1}{2}\Delta P_v^{STEQ} + P_v^{EQ}\right] - \alpha\left|\Delta q_p^{STEQ}\right|\left[\frac{1}{2}\Delta P_p^{STEQ} + P_p^{EQ}\right]$$

where Δq_t^{STEQ} represents the change in end user demand.

Also,

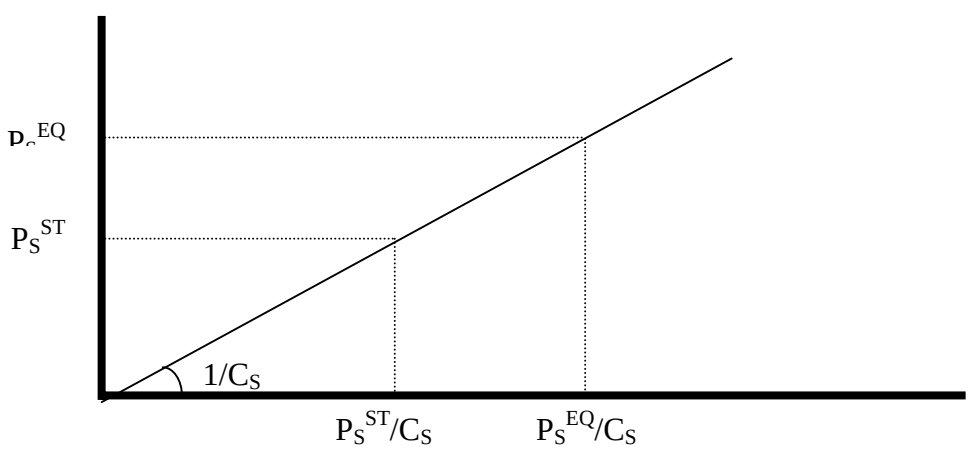
$$\Delta q_t^{STEQ} = -\gamma\Delta P_t^{STEQ}$$

Thus, we get

$$\Delta\left[CS + PS^e\right]^{STEQ} = -(1-\alpha)\frac{1}{2}\gamma\left(\Delta P_v^{STEQ}\right)^2 - \alpha\frac{1}{2}\gamma\Delta P_p^{STEQ}\left[P_p^{ST} + P_p^{EQ}\right]$$
$$= -\frac{(1-\alpha)4\theta_v{}^2 c_s{}^2\gamma(g+a\alpha)^2}{2\left[4c_s\gamma(g+\alpha)+1\right]^2} -$$
$$= -\frac{(1-\alpha)4\theta_v{}^2 c_s{}^2\gamma(g+a\alpha)^2}{2\left[4c_s\gamma(g+\alpha)+1\right]^2}$$
$$-\frac{\alpha\theta_v c_s\gamma(g+a\alpha)}{2(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]}\left[\frac{\theta_v c_s\left[a\alpha\left(4c_s\gamma(g+\alpha)+3\right)+2g\right]}{2(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]} + \frac{c_s\alpha\theta_p}{2(c_s\gamma\alpha+1)}\right]$$
$$= -\frac{\theta_v{}^2 c_s{}^2\gamma(g+a\alpha)}{2(c_s\gamma\alpha+1)^2\left[4c_s\gamma(g+\alpha)+1\right]^2}\left[4g(c_s\gamma\alpha+1)(g+a\alpha) + 2a\alpha(2c_s\gamma\alpha(g+\alpha)+\alpha) + g\alpha\right]$$
$$< 0$$

Similarly, from figure 1.A.1 below, we have

Figure 1.I.1: Storage Surplus



$$\begin{aligned}\Delta StorageSurplus^{STEQ} &= StorageSurplus^{ST} - StorageSurplus^{EQ} \\ &= -\left[\frac{P_s^{ST}}{c_s}\left|\Delta P_s^{STEQ}\right| + \frac{1}{2c_s}\left|\Delta P_s^{STEQ}\right|^2\right] \\ &= -\frac{\left|\Delta P_s^{STEQ}\right|}{2c_s}\left[P_s^{ST} + P_s^{EQ}\right]\end{aligned}$$

where

$$\Delta P_s^{STEQ} = P_s^{ST} - P_s^{EQ}$$

We have:

$$\begin{aligned}\Delta StorageSurplus^{STEQ} &= -\frac{1}{2c_s}\frac{\theta_v c_s(g+a\alpha)(2c_s\gamma\alpha+1)}{(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]}\left[\frac{\theta_v c_s\left[a\alpha\left(4c_s\gamma g-1\right)-2g\left(2c_s\gamma\alpha+1\right)\right]}{2(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]}+\frac{\theta_v c_s a\alpha}{2(c_s\gamma\alpha+1)}\right] \\ &= -\frac{1}{2}\frac{\theta_v^{\,2}c_s(2c_s\gamma\alpha+1)}{(c_s\gamma\alpha+1)^2\left[4c_s\gamma(g+\alpha)+1\right]^2}\left[g(2c_s\gamma\alpha(a-1)-1)+2a\alpha c_s\gamma(g+\alpha)\right] \\ &< 0\end{aligned}$$

Hence, the relative social welfare is given by

$$\begin{aligned}\Delta SW^{STEQ} &= \Delta\left[CS+PS^e\right]^{STEQ} - \Delta StorageSurplus^{STEQ} \\ &= -\frac{\theta_v^{\,2}c_s(g+a\alpha)}{2(c_s\gamma\alpha+1)^2\left[4c_s\gamma(g+\alpha)+1\right]^2}\begin{bmatrix}4c_s\gamma g(c_s\gamma\alpha+1)(g+a\alpha)+2c_s\gamma a\alpha(2c_s\gamma\alpha(g+\alpha)+\alpha)+c_s\gamma g\alpha \\ -g(2c_s\gamma\alpha+1)(2c_s\gamma\alpha(a-1)-1)-2a\alpha c_s\gamma(g+\alpha)(2c_s\gamma\alpha+1)\end{bmatrix} \\ &= -\frac{\theta_v^{\,2}c_s(g+a\alpha)}{2(c_s\gamma\alpha+1)^2\left[4c_s\gamma(g+\alpha)+1\right]^2}\begin{bmatrix}(c_s\gamma\alpha+1)\left[4c_s\gamma g(g+a\alpha)-g(2c_s\gamma\alpha(a-1)-1)-2a\alpha c_s\gamma(g+\alpha)\right]+ \\ 2c_s\gamma a\alpha(2c_s\gamma\alpha(g+\alpha)+\alpha)+c_s\gamma g\alpha-c_s\gamma\alpha g(2c_s\gamma\alpha(a-1)-1) \\ -2a\alpha c_s\gamma(g+\alpha)c_s\gamma\alpha\end{bmatrix} \\ &= -\frac{\theta_v^{\,2}c_s(g+a\alpha)(c_s\gamma\alpha+1)}{2(c_s\gamma\alpha+1)^2\left[4c_s\gamma(g+\alpha)+1\right]^2}\left[4c_s\gamma g(g+a\alpha)-g(2c_s\gamma\alpha(a-1)-1)-2a\alpha c_s\gamma(g+\alpha)+2c_s\gamma\alpha(g+a\alpha)\right]\end{aligned}$$

Simplification leads to:

$$\Delta SW^{STEQ} = -\frac{\theta_v^{\,2}c_s(g+a\alpha)g}{2(c_s\gamma\alpha+1)\left[4c_s\gamma(g+\alpha)+1\right]} < 0$$

That is, the equivalent contract structure leads to a higher social welfare level than the short term contract structure.

Appendix 1.G: Derivation of solution under long term contract structure with investment decision made simultaneously

This appendix derives the market equilibrium in the presence of storage. The problem facing the monopolist pipeline is given by:

$$\underset{P_v, P_p}{Max}(1-\alpha)P_v\left[\theta_v - \gamma P_v + \frac{P_p - P_v}{c_s(1-\alpha)}\right] + (\alpha P_p - k)\left[\theta_p - \gamma P_p - \frac{P_p - P_v}{c_s\alpha}\right]$$

The resulting First Order Conditions (FOC) are given by:

$$\theta_v c_s(1-\alpha) + 2P_p - 2P_v\left(c_s\gamma(1-\alpha)+1\right) - \frac{k}{c_s\alpha} = 0$$

$$\theta_v a c_s\alpha + 2P_v - 2P_p\left(c_s\gamma\alpha+1\right) + k(c_s\gamma + \frac{1}{\alpha}) = 0$$

From the first equation, we have:

$$2P_p = 2P_v\left(c_s\gamma(1-\alpha)+1\right) - \theta_v c_s(1-\alpha) + \frac{k}{\alpha}$$

and into the second equation leads to:

$$\begin{aligned} P_v^{LT} &= \frac{\theta_v\left((1-\alpha)(c_s\gamma\alpha+1) + a\alpha\right)}{2\gamma\left(c_s\gamma\alpha(1-\alpha)+1\right)} \\ &= \frac{\theta_v\left(g + a\alpha\right)}{2\gamma\left(g+\alpha\right)} \end{aligned}$$

Thus, we have:

$$\begin{aligned} P_p^{LT} &= \frac{\theta_v\left[(1-\alpha) + a\alpha\left(c_s\gamma(1-\alpha)+1\right)\right]}{2\gamma\left(c_s\gamma\alpha(1-\alpha)+1\right)} + \frac{k}{2\alpha} \\ &= \frac{\theta_v\left[g - (1-\alpha)c_s\gamma\alpha + a\alpha\left(c_s\gamma(1-\alpha)+1\right)\right]}{2\gamma\left(g+\alpha\right)} + \frac{k}{2\alpha} \\ &= \frac{\theta_v\left(g + a\alpha + (1-\alpha)c_s\gamma\alpha(a-1)\right)}{2\gamma\left(g+\alpha\right)} + \frac{k}{2\alpha} \end{aligned}$$

Similarly, we get:

$$\begin{aligned} Q_s^{LT} &= \frac{P_p - P_v}{c_s} \\ &= \frac{\theta_v(1-\alpha)\alpha(a-1)}{2\left(g+\alpha\right)} + \frac{k}{2c_s\alpha} \end{aligned}$$

and

$$
\begin{aligned}
q_p^{*LT} &= \theta_p - \frac{\theta_v \gamma\left(g + a\alpha + (1-\alpha)c_s\gamma\alpha(a-1)\right)}{2\gamma(g+\alpha)} - \frac{\theta_v(1-\alpha)\alpha(a-1)}{2(g+\alpha)\alpha} - \frac{k}{2\alpha}\left[\gamma + \frac{1}{c_s\alpha}\right] \\
&= \frac{\theta_v\left(2a(g+\alpha) - g - a\alpha - (a-1)g\right)}{2(g+\alpha)} - \frac{k}{2\alpha}\left[\gamma + \frac{1}{c_s\alpha}\right] \\
&= \frac{\theta_p}{2} - \frac{k}{2\alpha}\left[\gamma + \frac{1}{c_s\alpha}\right]
\end{aligned}
$$

Also,

$$
\begin{aligned}
q_v^{*LT} &= \theta_v - \frac{\theta_v\gamma(g+a\alpha)}{2\gamma(g+\alpha)} + \frac{\theta_v(1-\alpha)\alpha(a-1)}{2(g+\alpha)(1-\alpha)} + \frac{k}{2c_s\alpha(1-\alpha)} \\
&= \frac{\theta_v\left(2(g+\alpha) - g - \alpha\right)}{2(g+\alpha)} + \frac{k}{2c_s\alpha(1-\alpha)} \\
&= \frac{\theta_v}{2} + \frac{k}{2c_s\alpha(1-\alpha)}
\end{aligned}
$$

Chapter 2:

Capacity Rights, Contracts and Storage with Uncertainty

2.1. Introduction

The last decade has seen the restructuring of infrastructure sectors that have been vertically integrated "natural" monopolies. In the energy field, these include electric power and natural gas. This restructuring process seeks to differentiate potentially competitive segments (i.e. electricity generation and natural gas production) from natural monopoly or network infrastructure segments (i.e. electric transmission and gas pipeline networks). Restructuring entails price and entry deregulation in the potentially competitive segments, while the network segments continue to be subject to some form of regulation of prices, entry and quality. This new paradigm of industrial organization aims at guaranteeing suppliers in the competitive segments a fair and equal access to the network segments in order to supply their services in competition with their rivals.

In order to secure the efficiency of this new paradigm, a mechanism must be implemented to guarantee the efficient utilization of scarce network infrastructure capacity. From an economic point of view, market determined access prices are usually preferred over administrative rationing mechanisms, as these prices provide the economic signals that should guide additional capacity investments. One of the difficulties in implementing such market mechanisms is that the operator/owner of the network is a monopoly, and as such is bound to exploit its position if left unregulated. The monopoly cannot be trusted to set the right prices or make the right investment decisions. However, the design of regulatory mechanisms also proves troublesome as asymmetric information necessarily limits the ability of regulators to provide the right incentives.

This chapter, as the first one, exploits the storability characteristic of natural gas to analyze the extent that a pipeline can extract monopoly rents in a capacity rights market if left unregulated. The first chapter analyzed the case of perfect certainty. We saw that storage, by allowing end-users to bypass the pipeline in the peak, introduces the pipeline in the valley as a competitor to the pipeline in the peak. As a result, the pipeline's ability to extract monopolist rents is reduced, and social welfare is increased. This competitive effect of storage seems to provide support for market over regulatory mechanisms in providing the right incentives to the pipeline[21].

The extent of this competitive effect of storage and the extent that the monopolist pipeline can limit it, greatly depends on the market structure of the capacity rights market. We analyzed three possible structures: (i) a long term structure with a seasonal component, where the pipeline can commit to forward sales of capacity rights, (ii) a short term contract structure where the pipeline sells capacity rights at the beginning of each period, and (iii) a long term contract with no seasonal component. The first two structures entail a separate right for valley and peak times. End users will have a right to transport gas during the valley, which is not valid for the peak. Because of seasonalities in demand, end users will buy more rights in the peak than in the valley. In contrast, the

[21] Because the storability of electricity as pumped storage is very limited, this conclusion cannot be extended to the electricity sector.

third structure makes no distinction between rights for valley and peak times; they are equivalent as the number of capacity rights is equal in both valley and peak times.

The model analyzed two scenarios. The first assumed infrastructure is sunk, with capacity not binding in the peak. The model *unambiguously* showed that the competitive effect of storage is greater with the short term contract than with the long term contract with a seasonal component. That is, the latter allows the pipeline to limit more effectively the competitive effect of storage than the former. This is so because, through forward sales, the monopolist pipeline incorporates the long run elasticity of demand into its maximization problem. That is, forward sales allow the monopolist to incorporate not only the effects of valley prices, but also of peak prices, on end-users' decision to bypass the pipeline in peak times and its effect on valley profits. With a short term contract structure, however, the pipeline monopolist does not fully internalize the effect of peak prices on valley profits as the monopolist's problem in the peak takes the valley price as given. With the short term structure, the pipeline loses its ability to coordinate between the peak and valley periods, and can only react to valley prices in the peak. Moreover, a long term contract structure with no seasonal component, *unambiguously* led to higher social welfare at high levels of seasonalities, than the other two structures. Indeed, at high levels of seasonalities, capacity binds in the valley driving valley price to zero, and thus creating an enormous competitive effect of storage.

The second scenario analyzed assumes no infrastructure, and thus focuses on the investment decision by a monopolist pipeline. In this scenario, however, a short term contract structure leads to the same equilibrium as the long term contract structure with a seasonal component. This is so because, when determining the investment level, the monopolist pipeline effectively sells capacity rights forward for the peak period. In other words, the pipeline's ability to coordinate the maximization problem in the peak and valley periods, which was lost under the short term structure in the first scenario, is regained through the investment decision. Again, we saw that a long term contract structure with no seasonal component lead to higher social welfare for high levels of seasonalities.

In this second chapter, we expand our analysis by incorporating uncertainty. We model uncertainty with respect to peak end-user demand. The main effect of uncertainty is that it limits the competitive effect of storage. The reason is that the storage injection decision is made based on expected peak price. As such, *ex-post*, there is not enough storage injected if peak demand turns out as high, and there is overinjection if peak demand turns out as low. That is, e*x-post*, the amount of storage is never optimal, hindering the competitive effect of storage in relation to the certainty case. Moreover and more interestingly, uncertainty also changes the relative value of short term and long term with a seasonal component contracts from a social welfare point of view. Unlike the certainty case, short term contracts might prove more detrimental to social welfare than a long term contract. The main reason for this is that short term contracts give the flexibility to pipeline operators to adapt once uncertainty unfolds, which can be exploited, *ex-post*, in detriment of end-users.

The analysis presented here also extends to the investment decision case, when there is no infrastructure in place. Again, uncertainty changes the relative value of short term and long term with a seasonal component contracts. Short term contracts not only give the monopolist the flexibility to adjust to the outcome of uncertainty, but also the ability to sell capacity rights forward through the investment decision. As a result, long term contracts with no seasonal component *unambiguously* dominate short term contracts from a social welfare point of view.

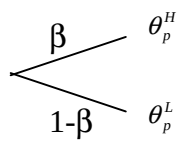
The second section of the chapter will present the model, as well as argue that uncertainty limits the competitive effect of storage. The third section will present the scenario with infrastructure in place. The fourth section will concentrate on the investment decision.

2.2. The Model

The model presented here presents small variations over the model presented in the first chapter. The model assumes two periods: valley and peak. Both periods are of equal length. Each period, end user demand for natural gas is given by:

$$Q_t = \theta_t - \gamma P$$

for t=v,p for valley and peak respectively. θ_t represents the seasonal component of end-user demand. We assume uncertainty with regard to θ_p, as depicted below:



with β<1, representing the probability of a high peak end user demand. We assume

$$\theta_p^H > \theta_p^L > \theta_v$$

As in the first chapter, pipeline sector is assumed to be monopolistic and the storage sector assumed to be perfectly competitive. We assume storage is located at the city gate. Gas is assumed to be injected during the valley and withdrawn during the peak, *after uncertainty unfolds*. The model can be thought of as storage operators (e.g. marketers) making storage decisions to take advantage of price differentials between peak and valley, buying capacity at valley prices and transporting it to the storage location in the valley period, and selling it at peak prices in the peak period.

Throughput demand, defined as end-user demand plus the storage effect (an injection in the valley and a withdrawal in the peak) is the demand facing the pipeline for capacity rights, and is thus,

$$Q'_v = \theta_v - \gamma P_v + Q_s^I$$
$$Q'^i_p = \theta_p^i - \gamma P_p^i - Q_s^{Wi}$$

for i=H,L, and where Q_s^I and Q_s^{Wi} represent gas injection into and gas withdrawals from storage, respectively.

Finally, investments are made in the first period, and are assumed to be immediately available for use. Investment costs are assumed to be linear in capacity with a constant investment cost of k.

The Storage Sector

For simplicity, we assume there is no cost of injecting gas into storage, but cost of *total gas withdrawn*[22] from storage, Q_s, is assumed to be quadratic[23]:

$$C_s(Q_s) = \frac{1}{2} c_s Q_s^{\ 2}$$

Storage operators take gas prices as given when making their storage decisions. Storage decisions are *irreversible* in that P_v, paid to transport gas in the valley for injection into storage, is sunk and storage operators cannot modify their storage injection decisions in the peak period. Let Q_s^I be the amount of storage injected into storage in the valley period. Given the storage cost structure, storage operators will withdraw all the gas from storage if the following condition holds:

$$P_p > c_s Q_s^I$$

In equilibrium, storage operators will withdraw all injected gas if uncertainty unfolds as high peak demand. Otherwise, storage injections would be suboptimal. That is, in equilibrium,

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[22] This chapter makes this somewhat unrealistic assumption to simplify the algebra in the equilibrium solutions. A more realistic assumption would be an injection cost with zero withdrawal costs. The results in this chapter are still valid with this assumption. This chapter discusses the results in light of this more realistic assumption, although it does not derive the equilibrium solutions.

[23] This is total cost for the entire storage sector. Alternatively, we can think of n storage operators having the same cost structure $C'_s=(1/2)c'_s Q_s^{\ 2}$, with $c'_s = c_s n$.. See the first chapter for a justification of this quadratic cost assumption.

$$P_p^H > c_s Q_s^I$$

In addition, in equilibrium, high peak price is larger than low peak price. In contrast, there are two possible cases for the quantity of gas withdrawn if uncertainty unfolds as low peak demand.

Case 1: A fraction of gas injected is withdrawn

In this first case, since capacity cost in the valley is sunk, the amount of gas withdrawn is:

$$Q_s^{WL} = \frac{P_p^L}{c_s} < Q_s^I$$

Thus, aggregate storage sector expected profits is given by:

$$-P_v Q_s^I + \beta\left[P_p^H Q_s^I - \frac{1}{2} c_s Q_s^{I\,2}\right] + (1-\beta)\left[P_p^L Q_s^{WL} - \frac{1}{2} c_s Q_s^{WL\,2}\right]$$

Since the storage sector is perfectly competitive, quantity injected in storage is given by the condition of zero marginal expected profit or:

$$-P_v + \beta\left[P_p^H - c_s Q_s^I\right] = 0$$

$$\Rightarrow Q_s^I = \frac{\beta P_p^H - P_v}{c_s \beta}$$

The above expression incorporates in the coefficient for P_p^H the fact that storage operators will be able to sell the last unit of gas put into storage only β of the time. Similarly, P_v represents the cost incurred in the purchase of capacity rights in the valley, for gas injection into storage. This cost will be incurred regardless of the outcome of the uncertainty. Also, the β in the denominator reflects the fact that withdrawal of this last unit of gas injected will occur only in the case of high peak demand.

Case 2: All gas injected is withdrawn

In this second case, all gas injected in storage is withdrawn. Thus, in equilibrium quantity injected into storage is given by[24]:

$$\Rightarrow Q_s^I = \frac{\beta P_p^H + (1-\beta)P_p^L - P_v}{c_s \beta}$$

That is, case 2 holds if:

$$P_p^H > P_p^L \geq c_s Q_s^I$$
$$\Rightarrow P_v \geq \beta(P_p^H - P_p^L) > 0$$

Therefore, from the above expression, two elements drive the two cases at hand:

1. *The level of uncertainty*: the larger uncertainty is, the larger the term (P_p^H- P_p^L) is, making case 1 more likely. One of the components in the storage decision is high peak demand. The larger it is, relative to low peak demand, the more storage will be driven by high peak demand making storage leftovers more likely in the case of low peak demand.

2. *The probability, β*: the larger it is, the larger the RHS in the above expression is, making case 1 more likely. Again, a higher probability of high peak demand will lead to a greater influence of high peak demand on the storage decision, storage leftovers more likely in the case of low peak demand.

From the above assumptions, the following conclusions can be drawn.

Corollary 2.1

Ex-post, the amount of gas injected into storage is never optimal from the point of view of end users.

[24] This case is equivalent to the case with injection costs and no withdrawal costs, since amount of gas injected into storage in that case is also $Q_s=[\beta P_s^H+(1-\beta)P_p^L-P_v]/c_s$.

Proof

Ex-post, the marginal benefit of storage is determined by the difference between peak and valley prices. That is,

$$MB_s^i = P_p^i - P_v$$

for i=H,L. The marginal cost of withdrawing the last unit of gas in storage is $c_s Q_s^I$. Thus, storage injections are not optimal *ex-post* if marginal benefit of storage is not equal to marginal cost.

Case 1

If uncertainty unfolds as high peak demand, then:

$$MC_s^H = c_s Q_s = \frac{\beta P_p^H - P_v}{\beta}$$
$$\Rightarrow MB_s^H - MC_s^H = \frac{(1-\beta)P_v}{\beta} > 0$$

If uncertainty unfolds as low peak demand, then:

$$MC_s^L = c_s Q_s^{WL} = P_P^L$$
$$\Rightarrow MB_s^L - MC_s^L = -P_v < 0$$

Case 2:

If uncertainty unfolds as high peak, then:

$$MC_s^H = c_s Q_s = \beta P_p^H + (1-\beta)P_p^L - P_v$$
$$\Rightarrow MB_s^H - MC_s^H = (1-\beta)(P_p^H - P_p^L) > 0$$

Similarly, in the case of low peak demand,

$$MC_s^L = c_s Q_s = \beta P_p^H + (1-\beta)P_p^L - P_v$$
$$\Rightarrow MB_s^L - MC_s^L = -\beta(P_p^H - P_p^L) < 0$$

Q.E.D.

In the case of a high peak demand, then, *ex-post* in the case of high peak demand, there is *underinjection* into storage, as marginal benefit exceeds marginal cost. In contrast, in the case of low peak demand, there is *overinjection* into storage as marginal

cost exceeds marginal benefits. However, *ex-ante*, storage decision is efficient in that it incorporates the probability of high and low peak demand as well as price expectations. *Ex-post*, then, the competitive effect of storage is not optimally exploited. It is in this sense that the irreversibility of storage decision strengthens the monopolistic position of the pipeline in the presence of storage. This conclusion is summarized in the following proposition.

Proposition 2.1

Irreversibility of the storage decision limits the competitive effect of storage and hence enhances the monopolistic position of the pipeline.

Proof[25]

The magnitude of the competitive effect of storage can be proxied by the extent that the pipeline can extract monopolistic rents[26]. This proof shows that a monopolist pipeline extracts a higher expected profit with irreversibility than with full reversibility. In the case of full reversibility, storage operators can fully adjust their storage levels in the peak as a function of the uncertainty outcome. That is, in the case of a high peak demand, storage operators can make further injections at a cost of P_v, and in the case of low peak demand, they can sell the extra gas in storage at a price of P_v. *Ex-post*, storage level is always optimal from the point of view of end-users given price differentials. Thus, the pipeline expected profit in this full reversibility case is:

$$E(\Pi)^R = \beta\Pi^H + (1-\beta)\Pi^L$$

where Π^i represents the pipeline profit in the case of certainty for i=H,L.

In the case of irreversibility, the pipeline expected profit is given by:

$$\begin{aligned} E(\Pi)^{IR} &= P_v^{IR}Q_v^{IR} + \beta P_p^{H,IR}Q_p^{H,IR} + (1-\beta)P_p^{L,IR}Q_p^{L,IR} \\ &= \beta\left(P_v^{IR}Q_v^{IR} + P_p^{H,IR}Q_p^{H,IR}\right) + (1-\beta)\left(P_v^{IR}Q_v^{IR} + P_p^{L,IR}Q_p^{L,IR}\right) \end{aligned}$$

---

[25] Appendix 2.A proves this proposition for the assumption of zero withdrawal costs and positive injection costs.

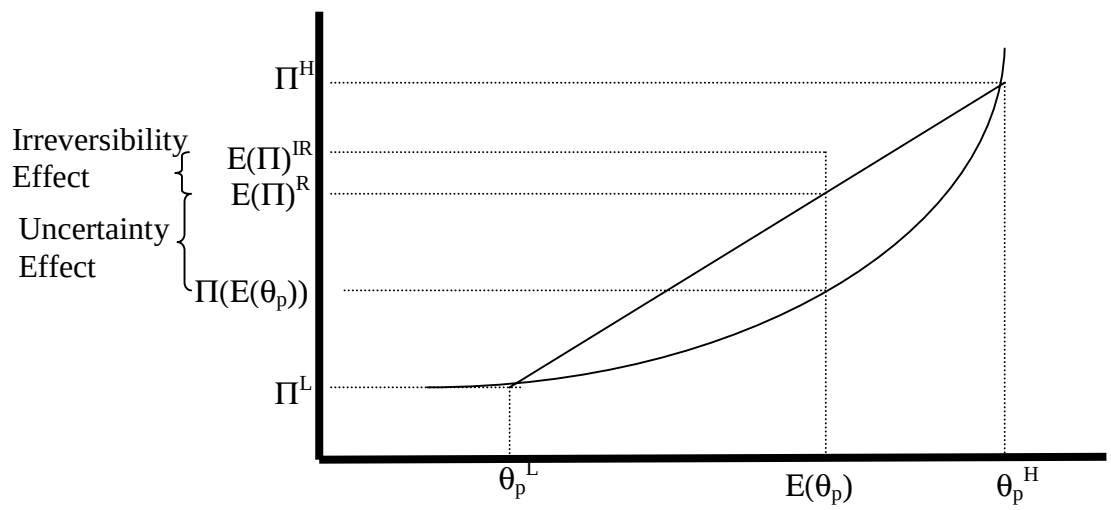
[26] Unlike the first chapter, this chapter deals with long term and short term contracts which differ only on their ability to sell capacity forward. Moreover, the only source of market imperfection is the monopolist position of the pipeline. Hence a contract structure that leads to higher profits for the pipeline necessarily leads to lower social welfare.

Following, Corollary II.1, *ex post*, storage injections are not optimal from the point of view of end users. Thus, we have:

$$E(\Pi)^{IR} > \beta\Pi^{H} + (1-\beta)\Pi^{L}$$

Furthermore, the convexity of Π with respect to θ_p (Appendix 2.B shows this) suggests that uncertainty works in favor of the monopolist as $E(\Pi)^R$ is higher than the profit with $E(\theta_p)$ for certain, $\Pi(E(\theta_p))$. That is, irreversibility strengthens the positive effect of uncertainty on pipeline expected profit, as depicted in figure 2.1 below. The convex function represents the pipeline profit in the certainty case. The straight line connecting the two points on the profit function represents the pipeline expected profit with full reversibility of the storage decision.

Figure 2.1: The Effect of Irreversibility and Uncertainty



Q.E.D.

It is important to note that this model assumes no economic life after the second period. This, of course, is unrealistic. However, these conclusions would still hold in a multicycle model. In particular, storage injections would be higher as the gas remaining in storage in the case of low peak demand could be used for the following valley-peak cycle. This would tend to diminish the positive effect of irreversibility on pipeline expected profit.

Although, the above corollary and proposition are general enough to apply to the different market structures in the first chapter, uncertainty also has some other implications that affect the relative value of the different market structures from a social welfare point of view. In the next paragraphs, we will analyze these implications for two contract structures: (i) the long term contract structure with a seasonal component, and (ii) the short term contract structure. It is important to note that in this model, the only source of market imperfection is the monopolistic position of the pipeline As such any contract structure that enables the pipeline to increase its profitability will conversely decrease social welfare. For this reason, the focus is on pipeline profits when determining the welfare effects of the different market structures. As in the first chapter, this chapter analyzes two scenarios: the first assumes infrastructure is sunk, and the second concentrates on the investment decision by the monopolist pipeline. Finally, this chapter focuses on the case where storage withdrawals under low peak demand are only a fraction of total gas injected into storage (case 1 in the above discussion). There are two reasons for this emphasis. First, this chapter argues that uncertainty changes the relative value of contracts. Cases of low uncertainty levels (e.g. case 2) can be proxied by the analysis in the first chapter with certainty while this chapter concentrates on high level of uncertainty. Second, uncertainty in the natural gas industry is primarily driven by weather uncertainty, which is highly volatile. Thus, case 1 seems to present a more realistic depiction of the natural gas industry.

2.3. Infrastructure in Place

Here we assume, pipeline infrastructure is sunk and, furthermore, that capacity is so large that it is never binding. We will first analyze the equilibrium with no storage, and then the equilibrium with storage under a short term contract and a long term contract structures. In our analysis of the certainty case, we saw that with no storage, both contract structures lead to the same equilibrium. However, with storage, the long term contract structure *unambiguously* leads to higher pipeline profits and thus to lower social welfare benefits than a short term structure. With a long term structure, the pipeline

monopolist takes the elasticity of peak demand into account when determining how many capacity rights to sell in the valley. This way, the monopolist is able to coordinate better the peak and valley problems and thus limit more effectively the competitive effect of storage. With uncertainty, this unambiguous benefit of short term contracts from a social welfare point of view is no longer valid, as will be explained in the next paragraphs.

It is important to note some characteristics of the long term contract structure under uncertainty. As in the certainty case, the monopolist sells capacity rights for both valley and peak periods at the same time. That is, when selling capacity rights for valley times, the monopolist sells forward capacity rights for the peak period. There is a seasonal component to the contract. The pipeline monopolist is committed to the contract and does not issue more rights once the uncertainty unfolds. However, in the context of uncertainty, this contract could take two forms, one with state a contingent clause and the other without it. With a state contingent contract, the monopolist can differentiate rights not only between peak and valley periods, but also between the different uncertainty outcomes in the peak. Such a contract gives full flexibility (i.e. coordination across time and outcomes) to the monopolist and thus represents the best possible outcome for the pipeline operator. In this report, however, we will concentrate on long term contracts with *no* contingent clauses. This is a more realistic assumption for two reasons: (i) writing a contract that stipulates responsibilities in all possible outcomes can be prohibitively expensive, and (ii) even if it were possible to write such a contract, the outcomes would not necessarily be observed by all interested parties making such contract unenforceable.

2.3.1. The No Storage Market Equilibrium

2.3.1.1. The Long Term Contract Structure

The optimal mechanism consists in determining the quantity of capacity rights[27] for the valley and the peak so as to maximize monopolist profits.

$$\underset{Q_v, Q_p}{Max} \frac{Q_v}{\gamma}(\theta_v - Q_v) + \beta \frac{Q_p}{\gamma}(\theta_p^H - Q_p) + (1-\beta)\frac{Q_p}{\gamma}(\theta_p^L - Q_p)$$

The solution to this problem is given by:

$$Q_v = \frac{\theta_v}{2}$$
$$P_v = \frac{\theta_v}{2\gamma}$$
$$Q_p = \frac{\beta\theta_p^H + (1-\beta)\theta_p^L}{2}$$
$$P_p^H = \frac{\theta_p^H + (1-\beta)(\theta_p^H - \theta_p^L)}{2\gamma}$$
$$P_p^L = \frac{\theta_p^L - \beta(\theta_p^H - \theta_p^L)}{2\gamma}$$

The resulting pipeline expected profit is given by:

$$E[\Pi]^{LT} = \Pi_v + \beta\Pi_p^H + (1-\beta)\Pi_p^L$$
$$= \frac{\theta_v^{\ 2} + \left[\beta\theta_p^H + (1-\beta)\theta_p^L\right]^2}{4\gamma}$$

We note that the pipeline expected profit is equal to total profit in the case with

$$\overline{\theta}_p = \beta\theta_p^H + (1-\beta)\theta_p^L$$

for certain.

2.3.1.2. The Short Term Contract Structure

In this market structure, the pipeline monopolist sells capacity at the beginning of each period. In the absence of storage there is no interaction between peak and valley periods and hence the problem facing the monopolist each period is given by:

$$\underset{P_t^i}{Max}\, P_t^i\left[\theta_t^i - \gamma P_t^i\right]$$

for t=v,p and i=H,L when t=p. The solution to this problem is given by:

---

[27] With no storage, end user demand is equal to throughput demand.

$$Q_v = \frac{\theta_v}{2}$$
$$P_v = \frac{\theta_v}{2\gamma}$$
$$Q_p^i = \frac{\theta_p^i}{2}$$
$$Q_p^i = \frac{\theta_p^i}{2\gamma}$$

for i=H,L. The resulting expected profit for the pipeline monopolist is given by:

$$E[\Pi]^{ST} = \Pi_v + \beta\Pi_p^H + (1-\beta)\Pi_p^L$$
$$= \frac{\theta_v^{\ 2} + \beta\theta_p^{H\,2} + (1-\beta)\theta_p^{L\,2}}{4\gamma}$$

We note also that the expected profit under a short term contract structure in the context of uncertainty is higher than in the context of average θ_p for certain. This comes as a direct consequence of the convexity of the profit function with respect to θ_p, in the certainty case. This is consistent with our earlier observation that uncertainty works to the benefit of the pipeline.

2.3.1.3. The Effect of Uncertainty

The first thing to note is that the equivalence between the short term contract and the long term contract structures, true in the context of certainty, is no longer so in the case of uncertainty[28]. Moreover, the short term contract structure seems to present a higher benefit to the pipeline operator. Namely,

$$E[\Pi]^{ST} - E[\Pi]^{LT} = \frac{\beta(1-\beta)(\theta_p^H - \theta_p^L)^2}{4\gamma} > 0$$

The reason for the higher profit level is that a short term contract structure gives the pipeline to ability to adjust once uncertainty unfolds. This added flexibility enables

[28] In fact, the equivalence still holds in the context of uncertainty if we consider a long term contract with contingent clauses.

the pipeline to price monopolistically in all periods, regardless of the outcome of uncertainty. This is not true under a long term contract structure as the pipeline must decide *ex-ante*, the number of rights to sell. *Ex-post*, the equilibrium under this contract structure does not coincide with the monopolistic outcome in either state of nature in the peak. Furthermore, the increased profitability under a short term contract structure increases with the variance of peak demand. Indeed, this is indeed as expected. With low variance, the value of the added flexibility under a short term contract is low as both states of the world look more similar. These observations can be summarized in the following proposition.

Proposition 2.2

In the absence of storage, a short term contract structure leads to higher expected profits for the pipeline, and hence to lower social benefits than a long term contract structure with no contingency clause.

2.3.2. The Storage Market Equilibrium

In the certainty case, we saw that a long term contract structure unambiguously leads to a lower pipeline profits and hence higher social benefits than a short term contract structure. The reason for this is that a long term contract structure allows the pipeline to incorporate the peak elasticity of demand into its maximization problem, and thus coordinate the peak and valley pricing problem. This coordination allows the pipeline to more effectively limit the competitive effect of storage. However, from our discussion above, a short term contract structure under uncertainty can be beneficial to the pipeline as it adds flexibility to adjust to uncertainty outcomes *ex post*. In the following paragraphs, we want to understand more this trade off between a short term contract and a long term contract structures when storage is present. More specifically, we want to determine the conditions under which the value of this added flexibility under a short term contract structure is sufficiently large that it makes a long term contract structure less profitable for the pipeline, contrary to our conclusion in the certainty case.

2.3.2.1. The Long Term Contract Structure

As noted earlier, storage introduces interaction between valley and peak times that the monopolist must take into account. Moreover, with uncertainty and period under a long term contract structure, the monopolist must consider that only one set of rights are valid for the peak period regardless of the uncertainty outcome. That is, the pipeline does not have full flexibility in the contract structure as contingency clauses would entail. This contract is not the best that a monopolist can do.

Mathematically, the optimal number of capacity rights to sell in the peak and valley periods is given by:

$$\underset{P_v, P_p^H, P_p^L}{Max}\ P_v\left[\theta_v - \gamma P_v\right] + \beta P_p^H\left[\theta_p^H - \gamma P_p^H\right] + (1-\beta)P_p^L\left[\theta_p^L - P_p^L\right] - \beta Q_s^I(P_v, P_p^H)\left(P_p^H - P_v\right)$$
$$- (1-\beta)Q_s^{WL}(P_p^L)\left(P_p^L - P_v\right) + (1-\beta)P_v\left[Q_s^I(\cdot) - Q_s^{WL}(\cdot)\right]$$

subject to:

$$\theta_p^H - \gamma P_p^H - Q_s^I(P_v, P_p^H) = \theta_p^L - P_p^L - Q_s^{WL}(P_p^L)$$

The constraint suggests that throughput demand in both states of the world be equal. The resulting Lagrangean is given by:

$$\text{l} = \left[P_v\left(\theta_v - \gamma P_v\right)\right] + \left[\beta P_p^H\left(\theta_p^H - \gamma P_p^H\right)\right] + \left[(1-\beta)P_p^L\left(\theta_p^L - P_p^L\right)\right] - \left[\beta Q_s^I(\cdot)\left(P_p^H - P_v\right)\right]$$
$$- \left[(1-\beta)Q_s^{WL}(\cdot)\left(P_p^L - P_v\right)\right] + \left[(1-\beta)P_v\left(Q_s^I(\cdot) - Q_s^{WL}(\cdot)\right)\right]$$
$$- \left[\lambda\left(\theta_p^H - \gamma P_p^H - Q_s^I(\cdot) - \theta_p^L + P_p^L + Q_s^{WL}(\cdot)\right)\right]$$

The Lagrangean presents the five effects that the pipeline operator must take into account:

- The first three bracket terms represent the expected end-user demand
- The fourth and fifth brackets represent, respectively, the loss of revenue stemming from storage usage in the case of high peak demand and low peak demand.
- The sixth term represents the *ex-post* overinjection that occurs in the case of low peak demand. This is a positive term because it represents a revenue in the valley coming and no corresponding decrease of sales in the peak.

- The last term represents the effect of having no contingency clauses in the contract.

Appendix 2.C shows the derivation of the solution to this problem. For notational simplicity, we put the solution as a function of equilibrium valley price:

$$P_v^{LT} = \frac{c_s \beta}{2(sr-1)}\left[s\theta_v + \theta_p^H\right]$$

with $s=c_s\gamma+1$. The LT in the superscript denotes the long term structure. The resulting peak prices are

$$P_p^{HLT} = \frac{1}{2\beta s}\left[c_s\beta\left(2\theta_p^H - \bar{\theta}_p\right) + 2P_v^{LT}\right]$$

$$P_p^{LLT} = \frac{c_s}{2s}\left[2\theta_p^L - \bar{\theta}_p\right]$$

And expected peak price is:

$$E(P_p)^{LT} = \frac{1}{2s}\left[c_s\bar{\theta}_p + 2P_v^{LT}\right]$$

The resulting storage injection (equivalent to storage withdrawal in the high peak) and storage withdrawal in the low peak are respectively given by:

$$Q_s^{ILT} = \frac{1}{2\beta s c_s}\left[c_s\beta\left(2\theta_p^H - \bar{\theta}_p\right) - 2P_v^{LT}(s-1)\right]$$

$$Q_s^{WLLT} = \frac{1}{2s}\left(2\theta_p^L - \bar{\theta}_p\right)$$

The resulting throughput demands are:

$$Q_v^{LT} = \frac{1}{2s}\left(2(s\theta_v + \theta_p^H) - \bar{\theta}_p\right)$$

$$Q_p^{LT} = \frac{\bar{\theta}_p}{2}$$

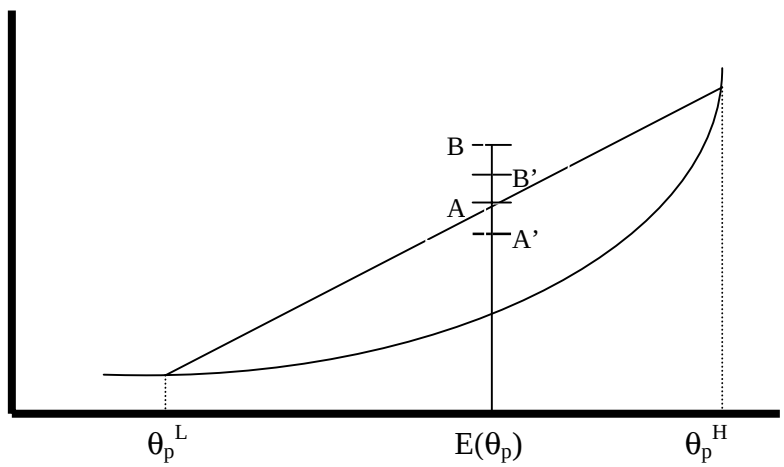
With $r=c_s\gamma\beta+1$. Finally, pipeline expected profits are:

$$E(\Pi)^{LT} = \frac{P_v^{LT}}{2s}\left[s\theta_v + \theta_p^H - \bar{\theta}_p\right] + \frac{\bar{\theta}_p}{4s}\left[c_s\bar{\theta}_p + 2P_v^{LT}\right]$$

There are two elements to consider in this contract structure: (i) the irreversibility of storage decision, which benefits the pipeline as discussed in Proposition 2.1, and (ii) the no-contingency clause of the contract structure, which goes in detriment of the

pipeline. This second element is represented by the constraint in the pipeline's maximization problem. These two elements can be illustrated in figure 2.2 below.

Figure 2.2: Irreversibility and No-contingency clauses in Long Term Contracts



Again, the convex function depicts the pipeline's profit in the certainty case under a long term contract structure[29]. The straight line connecting the two points on the profit function represents the pipeline's expected profit level with storage fully reversible *and* with contingency clauses. Point A represents, thus, the expected profit when both conditions are met. In contrast, point A' represents the expected profit with storage fully reversible and *no* contingency clauses. Because point A' represents a constrained maximization relative to point A, it entails a lower level of expected profits. Points B and B' are the corresponding expected profit levels when storage is irreversible. Again point B' entails a lower expected profit level than point B. It is precisely this difference, the cost of lesser flexibility for the pipeline, that can make a short term contract structure more attractive to the pipeline.

[29] Appendix 2.A shows this function to be convex.

2.3.2.2. The Short Term Contract Structure

We find the equilibrium for the short term contract structure via backward induction. Again, for notational simplicity we put our solution as a function of equilibrium valley price.

Peak Period Solution

In the case of low peak demand, the pipeline must maximize profits over residual demand. Pipeline must take valley price as given. In equilibrium, following our discussion earlier, storage withdrawals equals:

$$Q_s^{WL} = \frac{P_p^L}{c_s}$$

Thus the pipeline problem is:

$$\underset{P_p^L}{Max}\, P_p^L \left[\theta_p^L - \gamma P_p^L - Q_s^{WL}(P_p^L)\right]$$

The solution to this problem is:

$$P_p^{LST} = \frac{c_s \theta_p^L}{2s}$$

$$Q_p^{LST} = \frac{\theta_p^L}{2}$$

with $s=c_s\gamma+1$. Again, the ST superscript denotes the equilibrium solution for short term contracts. Storage withdrawals with low peak demand is thus,

$$Q_s^{WLST} = \frac{\theta_p^L}{2s}$$

Low peak profits equal,

$$\Pi_p^{LST} = \frac{c_s \theta_p^{L\,2}}{4s}$$

Similarly, in the case of high peak demand, the monopolist must maximize profits over residual demand. As discussed earlier, the amount of storage withdrawals equals storage injections in the peak:

$$Q_s^I = \frac{\beta P_p^H - P_v}{c_s \beta}$$

The problem is thus:

$$\underset{P_p^H}{Max}\, P_p^H \left[\theta_p^H - \gamma P_p^H - Q_s^I(P_p^H, P_v)\right]$$

The solution to this problem is:

$$P_p^{HST} = \frac{c_s\theta_p^H + P_v^{ST}}{2\beta s}$$

$$Q_p^{'HST} = \frac{c_s\theta_p^H + P_v^{ST}}{2\beta c_s}$$

The resulting storage withdrawals and high peak profits are thus:

$$Q_s^{IST} = \frac{c_s\theta_p^H + P_v^{ST}}{2\beta ss}\left[c\beta_s\theta_p^H - P_v^{ST}(2s-1)\right]$$

$$\Pi_p^{HST} = \frac{1}{4\beta^2 c_s s}\left[c_s\theta_p^H + P_v^{ST}\right]^2$$

Valley Period Solution

To solve the valley period problem, the monopolist takes the above solutions, as a function of P_v as given. The problem facing the monopolist is thus:

$$\underset{P_v}{Max}\, P_v\left[\theta_v - \gamma P_v + Q_s^I(P_v, P_p^H(P_v))\right] + \beta\Pi_p^H(P_v) + (1-\beta)\Pi_p^L(P_v)$$

Appendix 2.D shows the derivation of the solution to this problem. We find equilibrium valley price to be:

$$P_v^{ST} = \frac{c_s\beta}{4sr-3}\left[2(s\theta_v + \theta_p^H)\right]$$

The resulting valley throughput demand is thus:

$$Q_v^{'ST} = \frac{1}{2c_s\beta s}\left[c_s\beta(2s\theta_v + \theta_p^H) - (2sr-1)P_v^{ST}\right]$$

Finally, pipeline expected profits under this short term contract structure are:

$$E(\Pi)^{ST} = \frac{P_v^{ST}}{sc_s\beta}\left[c_s(s\theta_v + \theta_p^H) - P_v^{ST}(sr-1)\right] + \frac{1}{4sc_s\beta}\left[(c_s\beta\theta_p^H)^2 - P_v^{ST\,2}\right] + \frac{(1-\beta)c_s\theta_p^{L\,2}}{4s}$$

2.3.2.3. The Effect of Uncertainty

In the certainty case, we saw that the pipeline is *unambiguously* better off with a long term contract structure than with a short term contract structure. With uncertainty, however, this is not necessarily true. From our discussion above, the pipeline faces a trade-off between a short term and a long term contract structure. On the one hand, a long term contract structure allows for the incorporation of peak elasticity into the maximization problem in the valley. However, with no contingency clause, a long term contract structure does not allow the flexibility to adjust the decision once uncertainty unfolds. In contrast, a short term contract structure gives the pipeline the flexibility to react to the uncertainty outcome, although it does not allow for the incorporation of peak elasticity into the valley maximization problem. As the variance of θ_p increases, the value of the flexibility entailed by the short term contract structure increases. Thus, for large variances, a short term contract structure yields higher expected profits than a long term contract structure.

Proposition 2.3

A short term contract structure yields higher expected profits than a long term contract structure with no contingency clauses for large variances in θ_p. For small variances, the long term contract structure yields higher expected profits, as in the certainty case.

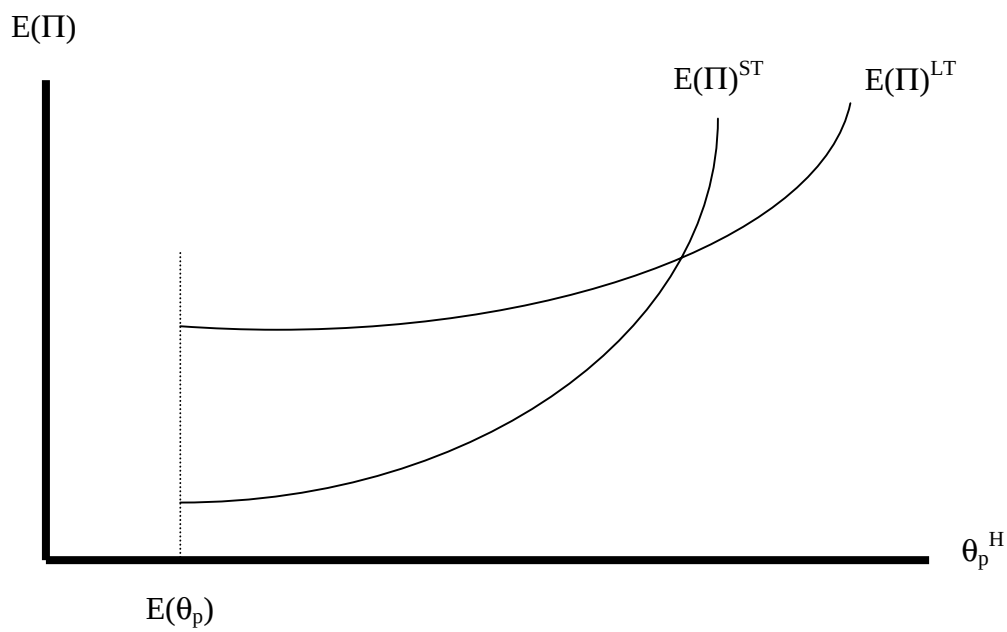
Proof

The first chapter shows that a long term contract structure leads to higher pipeline profits in the case of certainty. The certainty case proxies and proves the proposition with regard to low variances in θ_p. For the case of high variances in θ_p, comparative statics are performed on our above equilibrium solutions with respect to θ_p^H, while keeping expected θ_p constant. That is, an increase in θ_p^H with expected θ_p constant, represents an increase in the variance of θ_p. Appendix 2.E shows that the expected profits under a long and a short term contract structure are both convex with respect to θ_p^H. Thus, the following condition are sufficient to prove the proposition:

$$\frac{\partial^2 E(\Pi)^{ST}}{\partial \theta_p^{H\,2}} - \frac{\partial^2 E(\Pi)^{LT}}{\partial \theta_p^{H\,2}} > 0$$

This is indeed what we find in Appendix 2.E. This proposition is depicted in the figure 2.3 below.

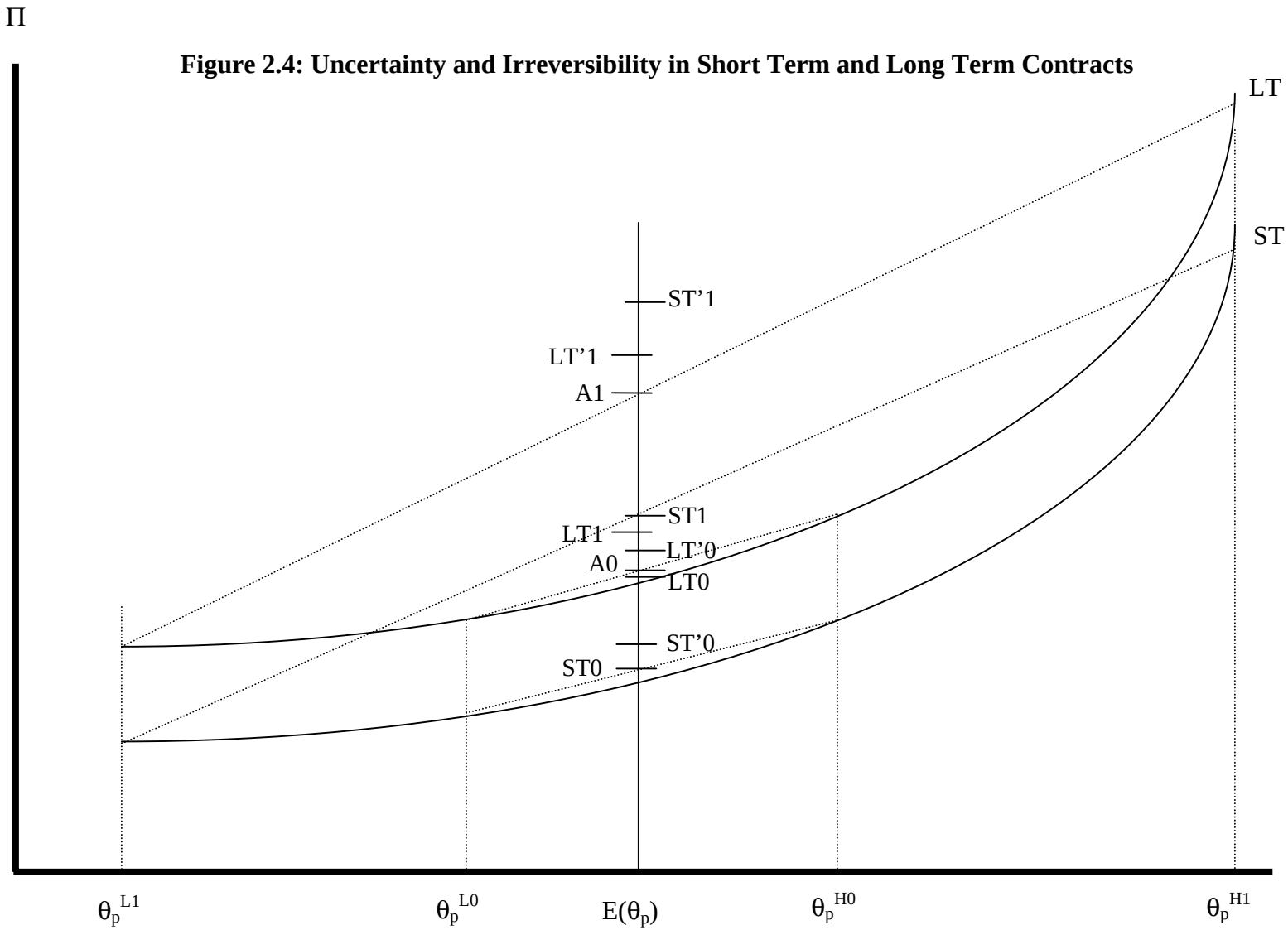
Figure 2.3: Profitability under Short Term and Long Term Contracts



Q.E.D.

In sum, uncertainty introduces two elements that must be analyzed: (i) the irreversibility of storage decision, (ii) the inability of the pipeline to include contingency clauses in long term contracts. These two elements are depicted in the figure 2.4 next page. The convex functions represent the profit functions in the certainty case under a long and a short term contract structure. Note that a long term contract *unambiguously* leads to a higher profit level. Two uncertainty structures are considered: the first with low variance (denoted by the subscript 0) and the second with high variance (depicted by the subscript 1). Both these structures have the same expected θ_p. Points LTi and STi (with i=0,1) represent the expected profits under a long term and a short term contract structure, respectively, with full reversibility of storage decision. Points LT'i and ST'i represent the corresponding expected profits with irreversibility of storage decision.

Figure 2.4: Uncertainty and Irreversibility in Short Term and Long Term Contracts



Following Proposition 2.1, the irreversibility of storage decision leads to higher expected profits than with full reversibility. In the graph this is represented by LTi> LT'i and STi> ST'i. Moreover, following Proposition 2.3, a long term contract with no contingency clauses leads to lower expected profits than one with contingency clauses. This is represented by Ai>LTi, where Ai represents the expected profit under a long term contract with contingency clauses and full reversibility of storage decision. Note that Ai lies on the ray connecting the two points on the profit function. From the figure 2.4, we see that with a high variance the effect of no contingency clauses is very large making a short term contract more attractive for the pipeline. Again, with such high variances, the value of a short term contract lies on the flexibility to adjust once uncertainty unfolds.

2.4. No Infrastructure in Place

We now turn our attention to the pipeline investment decision. We assume infrastructure is not sunk, and thus the pipeline operator must invest in pipeline capacity if it is to provide gas transportation services. In the following paragraphs, we derive the solution to the long term contract and short term contract structures. Our main conclusion that short term contracts provide an additional benefit to the pipeline, namely the flexibility to adjust to the uncertainty outcome, still holds. Moreover, this benefit of short term contracts is even stronger when we incorporate investment decision. Indeed, we find that short term contracts *unambiguously* leads to higher expected profits both in the absence and presence of storage. As in the certainty case, under a short term contract structure, the pipeline effectively sells forward capacity for high peak demand by making the investment decision in the valley simultaneous to determining the valley price. A short term contract allows the incorporation of high peak demand elasticity into its valley problem. That is, with a short term contract does not only allow the pipeline to have the flexibility to adjust to the uncertainty outcome, but it also allows him to coordinate his high peak and valley problems. However, this structure does not allow him to coordinate the low peak and the valley problems. It is precisely this added feature that makes the short term contract more attractive.

2.4.1. The No Storage Market Equilibrium

2.4.1.1. The Long Term Contract Structure

Under a long term structure with no contingency clauses, capacity is binding in the peak period regardless of the uncertainty outcome. Let K be the investment capacity. The problem facing the monopolist is given by:

$$\underset{Q_v, K}{Max} \frac{Q_v}{\gamma}(\theta_v - Q_v) + \beta \frac{K}{\gamma}(\theta_p^H - K) + (1-\beta)\frac{K}{\gamma}(\theta_p^L - K) - kK$$

The solution to this problem is given by:

$$Q_v^{LT} = \frac{\theta_v}{2}$$

$$P_v^{LT} = \frac{\theta_v}{2\gamma}$$

$$K^{LT} = \frac{\bar{\theta}_p - \gamma k}{2}$$

$$P_p^{HLT} = \frac{(2\theta_p^H - \bar{\theta}_p) + \gamma k}{2\gamma}$$

$$P_p^{LLT} = \frac{(2\theta_p^L - \bar{\theta}_p) + \gamma k}{2\gamma}$$

The resulting pipeline expected profit is given by:

$$E[\Pi]^{LT} = \Pi_v + \beta \Pi_p^H + (1-\beta)\Pi_p^L - kK$$

$$= \frac{\theta_v^{\,2}}{4\gamma} + \frac{1}{4\gamma}\left[\bar{\theta}_p - \gamma k\right]^2$$

As in the scenario with infrastructure in place, this solution is the same as the one with average peak demand for certain. Note that the term γk is in both peak prices, suggesting investment costs are paid by peak end-users regardless of the outcome of the uncertainty.

2.4.1.2. The Short Term Contract Structure

In contrast to the long term contract structure, we assume that the monopolist invests such that capacity is binding in the peak period only when the uncertainty unfolds

as high peak demand[30]. In the case of a low peak demand, the pipeline faces the following problem:

$$\underset{P_p^L}{Max}\, P_p^L \left[\theta_p^L - \gamma P_p^L\right]$$

The solution is the usual

$$Q_p^{LST} = \frac{\theta_p^L}{2}$$
$$P_p^{LST} = \frac{\theta_p^L}{2\gamma}$$
$$\Pi_p^{LST} = \frac{\theta_p^{L^2}}{4\gamma}$$

In the valley, the pipeline must choose valley prices and capacity. Again, let K be the investment variable. The valley problem is thus:

$$\underset{Q_v K}{Max} \frac{Q_v}{\gamma}(\theta_v - Q'_v) + \beta \frac{K}{\gamma}(\theta_p^H - K) - kK$$

The solution to this problem is given by:

$$Q_v^{ST} = \frac{\theta_v}{2}$$
$$P_v^{ST} = \frac{\theta_v}{2\gamma}$$
$$K^{ST} = \frac{\theta_p^H - (\gamma k/\beta)}{2}$$
$$P_p^{HST} = \frac{\theta_p^H + (\gamma k/\beta)}{2\gamma}$$

For $K>Q_p^L$, we need $(\theta_p^H - \theta_p^L) > \gamma k/\beta$. Note that the investment is paid only by end users in the high peak demand outcome. As such, the effective investment price is k/β, which incorporates the probability that investment will get repaid.

The resulting pipeline expected profit is given by:

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[30] If this is not true, then capacity will be binding in the both states of peak demand, and the outcome will be identical to long term contract structure.

$$E[\Pi]^{ST} = \Pi_v + \beta\Pi_p^H + (1-\beta)\Pi_p^L - kK$$
$$= \frac{\theta_v^{\ 2}}{4\gamma} + \frac{(1-\beta)\theta_p^{L^2}}{4\gamma} + \frac{\beta}{4\gamma}\left[\theta_p^H - \frac{\gamma k}{\beta}\right]^2$$

2.4.1.3. The Effect of Uncertainty

As in the first scenario, we conclude that the equivalency between the two structures found in the certainty case, is no longer valid with uncertainty. Moreover, comparing the equilibrium under the two structures leads to interesting results. First, a short term contract structure *unambiguously* leads to a higher investment level than the long term contract structure. Indeed, we have:

$$K^{ST} - K^{LT} = \frac{(1-\beta)}{2}\left[(\theta_p^H - \theta_p^L) - \frac{\gamma k}{\beta}\right] > 0$$

Note that this difference increases with the variance of θ_p. There are two issues at hand. On the one hand, under a short term contract, only high peak end users pay for the investment cost. As such the effective investment cost, as noted earlier, is k/β. This is not the case under a long term contract structure where peak end users pay for the investment cost regardless of the uncertainty outcome. This will tend to decrease investments with a short term contract relative to a long term contract. On the other hand, under a short term contract, investments are designed for *high* peak demand, θ_p^H. In contrast, under a long term contract, investments are designed for *average* peak demand. This will tend to increase investments under a short term contract relative to a long term contract. In balance, this second issue outweighs the first. This result has important implications if the aim of regulators is to provide incentives for pipeline investments (e.g. in infant markets with low pipeline penetration).

Second, a short term contract structure leads *unambiguously* to a higher expected profit than a long term contract. Indeed, we find:

$$E(\Pi)^{ST} - E(\Pi)^{LT} = \frac{\beta(1-\beta)}{4\gamma}\left[(\theta_p^H - \theta_p^L) - \frac{\gamma k}{\beta}\right]^2 > 0$$

We note that the dominance of short term contracts accentuates as the variance of θ_p increases. We summarize the above conclusion in the following proposition.

Proposition 2.4

In the absence of storage and with no infrastructure in place, a short term contract structure yields higher pipeline investments as well as higher expected profits than a long term contract structure. The difference in investment and profit levels are positively related to the variance in θ_p.

2.4.2. The Storage Market Equilibrium

In the certainty case, chapter one shows that the short term and long term contract structures yield the same solution when infrastructure is not in place. The reason for this is that the pipeline, by making the investment decision in the valley, effectively sells capacity rights forward for the peak period. That is, the investment decision hinders the ability of short term contracts to limit the competitive effect of storage, so much greater when infrastructure is sunk. Here we extend the analysis to incorporate uncertainty. As in the scenario with infrastructure sunk, we take long term contracts to have no contingency clauses. As in the no storage equilibrium, we find that short term contracts *unambiguously* lead to higher expected profit than long term contracts. The reason for this is that a short term contract structure offers an additional benefit to the pipeline beyond the flexibility to adjust to the uncertainty outcome, as discussed in the first scenario. In this scenario, a short term contract structure allows the pipeline, through the investment decision, to incorporate the demand elasticity of high peak into the valley maximization problem. That is, the investment decision allows the pipeline to move a step closer to his first best outcome. This outcome entails the flexibility to adjust to the

uncertainty outcome and the ability to incorporate high *and* low peak demand elasticities into his valley maximization problem[31].

2.4.2.1. The Long Term Contract Structure

The problem facing the monopolist is the same as that in the first scenario. We need only incorporate the investment cost. Mathematically, the optimal number of capacity rights to sell in the peak and valley periods is given by:

$$\underset{P_v, P_p^H, P_p^L}{Max}\ P_v\left[\theta_v - \gamma P_v\right] + \beta P_p^H\left[\theta_p^H - \gamma P_p^H\right] + (1-\beta)P_p^L\left[\theta_p^L - \gamma P_p^L\right] - \beta Q_s^I(P_v, P_p^H)\left(P_p^H - P_v\right)$$
$$-(1-\beta)Q_s^{WL}(P_p^L)\left(P_p^L - P_v\right) + (1-\beta)P_v\left[Q_s^I(\cdot) - Q_s^{WL}(\cdot)\right] - k\left[\theta_p^H - \gamma P_p^H - Q_s^I(\cdot)\right]$$

subject to:

$$\theta_p^H - \gamma P_p^H - Q_s^I(P_v, P_p^H) = \theta_p^L - P_p^L - Q_s^{WL}(P_p^L)$$

The constraint suggests that throughput demand in both states of the world be equal. Note that this is the same problem as in the first scenario. The last term in the second line is added reflecting investment costs. Appendix 2.F shows the derivation of the equilibrium solution to this problem. Again, for notational simplicity, we put the solution as a function of equilibrium valley price:

$$P_v^{LT} = \frac{c_s\beta}{2(sr-1)}(s\theta_v + \theta_p^H)$$

The resulting peak prices are

$$P_p^{HLT} = \frac{1}{2\beta s}\left[c_s\beta\left(2\theta_p^H - \bar{\theta}_p\right) + 2P_v^{LT}\right] + \frac{k}{2}$$
$$P_p^{LLT} = \frac{c_s\left(2\theta_p^L - \bar{\theta}_p\right)}{2s} + \frac{k}{2}$$

And expected peak price is:

[31] Of course, this first best outcome is achieved through a long term contract structure with contingent clauses.

$$E(P_p)^{LT} = \frac{1}{2s}\left[c_s\bar{\theta}_p + 2P_v^{LT}\right] + \frac{k}{2}$$

The resulting storage injection and storage withdrawal in the low peak are respectively given by:

$$Q_s^{ILT} = \frac{1}{2\beta s c_s}\left[c_s\beta\left(2\theta_p^H - \bar{\theta}_p\right) - P_v^{LT}\,2(s-1)\right] + \frac{k}{2c_s}$$

$$Q_s^{WLLT} = \frac{2\theta_p^L - \bar{\theta}_p}{2s} + \frac{k}{2c_s}$$

The resulting valley throughput demand and investment level are, respectively:

$$Q_v^{LT} = \frac{1}{2s}\left(s\theta_v + \theta_p^H - \bar{\theta}_p\right) + \frac{k}{2c_s}$$

$$K^{LT} = \frac{\bar{\theta}_p}{2} - \frac{sk}{2c_s}$$

Finally, pipeline expected profits are:

$$E(\Pi)^{LT} = \frac{P_v^{LT}}{2s}\left[s\theta_v + \theta_p^H\right] + \frac{c_s\bar{\theta}_p^{\,2}}{4s} - \frac{k\bar{\theta}_p}{2} + \frac{sk^2}{4c_s}$$

2.4.2.2. The Short Term Contract Structure

We find the equilibrium solution via backward induction. Again, for notational simplicity, we put our equilibrium solution as a function of equilibrium valley price.

Peak Period Solution

In the case of low peak demand, the pipeline faces the same problem as in the first scenario when infrastructure is in place. Namely, in equilibrium, we have:

$$P_p^{LST} = \frac{c_s\theta_p^L}{2s}$$

$$Q_p^{LST} = \frac{\theta_p^L}{2}$$

Storage withdrawals and profits are thus,

$$Q_s^{WLST} = \frac{\theta_p^L}{2s}$$

$$\Pi_p^{LST} = \frac{c_s \theta_p^{L^2}}{4s}$$

The ST superscript denotes equilibrium under a short term contract structure.

In the case of high peak demand, capacity (built in the valley period) is binding. Let K be the investment capacity. The resulting price and profit in the case of high peak demand are:

$$P_p^H = \frac{c_s \beta(\theta_p^H - K) + P_v}{\beta s}$$

$$\Pi_p^H = K \frac{c_s \beta(\theta_p^H - K) + P_v}{\beta s}$$

Valley Period Solution

Valley demand throughput is given by:

$$Q'_v = \frac{1}{c_s \beta s}\left[c_s \beta(s\theta_v + \theta_p^H) - c_s \beta K - P_v(sr - 1)\right]$$

To solve the valley period problem, the monopolist takes the above solutions, as a function of P_v and K, as given. The problem facing the monopolist is thus:

$$\underset{P_v, K}{Max}\, P_v Q'_v(K, P_v) + \beta \Pi_p^H(P_v, K) + (1-\beta)\Pi_p^L - kK$$

The First Order Conditions (FOC) are thus:

$$c_s \beta\left[s\theta_v + \theta_p^H\right] - 2(sr-1)P_v = 0$$

$$\frac{c_s \beta}{s}(\theta_p^H - 2K) - k = 0$$

In equilibrium, we find thus,

$$Q_s^{IST} = \frac{1}{2sc_s\beta}\left[c_s \beta \theta_p^H - P_v^{LT} 2(s-1)\right] + \frac{k}{2c_s\beta}$$

The resulting storage injection is thus,

$$P_v^{ST} = \frac{c_s \beta(s\theta_v + \theta_p^H)}{2(sr-1)}$$

$$K^{ST} = \frac{c_s \beta \theta_p^H - sk}{2c_s \beta}$$

The resulting valley throughput demand is thus:

$$Q_v^{*ST} = \frac{1}{2}\theta_v + \frac{k}{2c_s\beta}$$

Finally, expected profits are:

$$\begin{aligned} E(\Pi)^{ST} &= P_v^{ST} \cdot Q_v^{*ST} + \beta\Pi_p^{HST} + (1-\beta)\Pi_p^{LST} \\ &= \frac{P_v^{ST}}{2s}\left(s\theta_v + \theta_p^H\right) + \frac{c_s}{4s}\left[\theta_p^{L\,2}(1-\beta) + \beta\theta_p^{H\,2}\right] - \frac{k\theta_p^H}{2} + \frac{k^2 s}{4c_s\beta} \end{aligned}$$

<u>2.4.1.3. The Effect of Uncertainty</u>

As noted earlier, this chapter focuses on the case with partial storage withdrawals when uncertainty unfolds as low peak demand. Thus, the following conditions must hold:

$$\begin{aligned} & P_v^{LT} < \beta(P_p^{HLT} - P_p^{LLT}) \\ & \Rightarrow \frac{(s\theta_v + \theta_p^H)(s-1)}{2(sr-1)} < (\theta_p^H - \theta_p^L) \end{aligned}$$

for the long term structure, and:

$$\begin{aligned} & P_v^{ST} < \beta(P_p^{HST} - P_p^{LST}) \\ & \Rightarrow \frac{(s\theta_v + \theta_p^H)(s-1)}{(sr-1)} - \frac{sk}{c_s\beta} < (\theta_p^H - \theta_p^L) \end{aligned}$$

for the short term contract structure. Let T be the threshold such that:

$$T = Min\left[\frac{(s\theta_v + \theta_p^H)(s-1)}{(sr-1)} - \frac{sk}{c_s\beta}, \frac{(s\theta_v + \theta_p^H)(s-1)}{2(sr-1)}\right]$$

Thus, the analysis assumes:

$$T < (\theta_p^H - \theta_p^L)$$

so as to guarantee partial storage withdrawals under *both* contract structures, when uncertainty unfolds as low peak demand.

With the uncertainty range defined, uncertainty leads to different equilibrium outcomes, in contrast to the certainty case that leads to short term and long term contract structures yielding the same equilibrium. Comparing the two equilibrium conditions lead to some interesting results summarized in the following propositions.

Proposition 2.5

In the presence of storage and with no infrastructure in place, a short term contract structure induces lower pipeline investments at low uncertainty levels, and higher investments at high uncertainty levels.

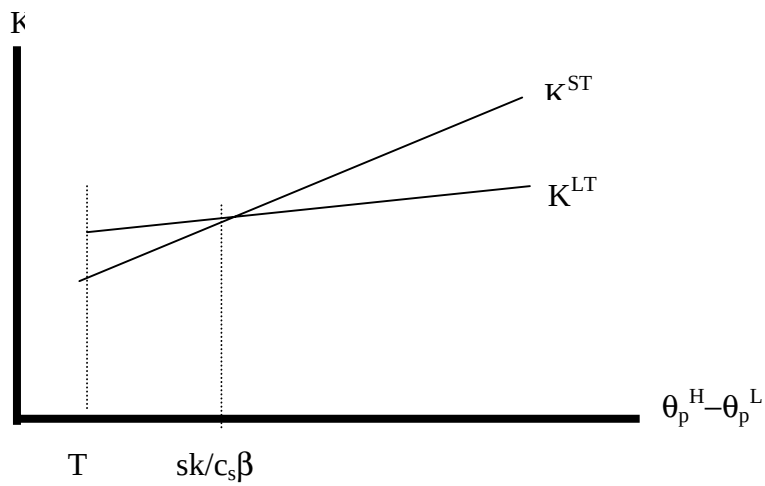
Proof

Appendix 2.G shows that:

$$K^{ST} - K^{LT} > 0 \Leftrightarrow \theta_p^H - \theta_p^L > \frac{sk}{c_s \beta}$$

Thus, for high uncertainty levels, a short term contract structure leads to higher investment levels, but for low uncertainty levels a long term contract structure leads to higher investment levels. Figure 2.5 below depicts this case:

Figure 2.5: Investment under Short Term and Long Term Contracts



Q.E.D.

As in the no storage equilibrium, there are two issues at hand here. First, the effective investment cost under a short term contract is k/β. Second, investments under a short term contract are designed for *high* peak demand, θ_p^H, whereas they are designed to *average* peak demand under a long term contract. With low variances, the two states of nature are very similar and hence a short term contract structure leads to lower investment levels because of the higher effective investment cost. In contrast, with high variances, a short term contract structure leads to higher investments because of the second issue.

Note that the above proof assumes:

$$\theta_p^H - \theta_p^L > \frac{sk}{c_s\beta} > T$$

If, on the other hand, investment costs are such that

$$\theta_p^H - \theta_p^L > T > \frac{sk}{c_s\beta}$$

then a short term contract structure always leads to higher investment levels.

Proposition 2.6

In the presence of storage and with no infrastructure in place, a short term contract structure unambiguously leads to higher expected profits than a long term contract structure.

Proof

Appendix 2.H shows that the difference in expected profits under a short term and long term contract structures are:

$$E(\Pi)^{ST} - E(\Pi)^{LT} = \frac{(1-\beta)c_s\beta}{4s}\left[\left(\theta_p^H - \theta_p^L\right) - \frac{sk}{c_s\beta}\right]^2 > 0$$

Q.E.D.

The intuition behind this proposition is that a short term contract does not only allow for the flexibility to adjust to the uncertainty outcome, but it also allows the pipeline, through the investment decision, to incorporate the demand elasticity of high peak into his valley maximization problem. In this manner, the pipeline can better "coordinate" the high peak and valley problems, and hence more effectively limit the competitive effect of storage on high peak demand. Short term contracts does not allow for the same coordination benefits with low peak demand. In the case of low peak demand, the pipeline can only react to valley prices and storage injections. In other words, a short term contract allows the pipeline to move a step closer to his first best position, characterized by the ability to distinguish between states of nature and the ability to fully coordinate the peak (both high and low) and valley problems. This first best position is attained through a long term contract structure with contingency clauses.

2.5. Conclusions

This chapter analyzes the impact of uncertainty on the competitive effect of storage. We saw that uncertainty, and more precisely the irreversibility of the storage decision, limits the competitive effect of storage. More interestingly, uncertainty changes the relative value of short term contracts vis-a-vis long term contracts. With infrastructure in place, there is a trade-off for the pipeline between the flexibility to adjust to the uncertainty outcome entailed by a short term contract structure, and the ability to incorporate peak demand elasticity in the valley problem entailed by a long term contract structure. At low variances, the second issue outweighs the first and, thus, a long term contract structure more effectively limits the competitive effect of storage. In contrast, at high variances the ability to adjust to uncertainty outcomes is more valuable, making short term contracts a better mechanism to limit the competitive effect of storage. That is, at low variances a short term contract structure seems to enhance social welfare, whereas at high variances the opposite holds. This would entail that there is no single answer to the most efficient market structure. It all depends on the nature of the market. In such markets with high uncertainty (perhaps maybe the Northeast corridor with wild variation in winter weather pattern) a long term contract structure might prove more beneficial. In contrast, in markets with low uncertainty about peak demand (for example, Florida) a short term contract structure can be more beneficial. It seems that end users can fairly easy adjust to these market structures. In markets with high variances, the need for risk hedging mechanisms is very clear, and long term contracts might be an avenue to hedge the risks. Similarly, in markets with low variance, the need for hedging mechanisms is very limited, and thus a short term contract structure could be implemented relatively easy.

The results with regard to the investment decision also raise interesting conclusions. This chapter, as well as the first one, clearly shows the benefits of encouraging storage facilities near natural gas markets. Moreover, it would seem that a long term market structure is the more efficient one, from a social welfare point of view, in the context of the pipeline investment decision, as it leads to lower pipeline profits. This is indeed very interesting since most investments are usually carried under long term

contracts so as to avoid any opportunistic behavior after the investments are done. However, policy makers need to understand that a long term contract structure might lead to a lower investment level if the market presents high variances. Thus long term contracts may hinder infrastructure development. Policy makers need to weight whether this is indeed desirable. Moreover, as discussed in the next chapter, long term contracts also allow a better allocation of risk and can thus lead to more efficient investment levels. Again, this might be at cost of lower investment levels. Contracts seem to have a dual role. First, they can strengthen the competitive effect of storage and, second can guide investment decisions. Unfortunately, these roles can be conflicting. There seems to be no right answer as to what the most efficient contracting regime is to encourage investments and competition by storage.

Appendix 2.A: Proof of Proposition 2.1 assuming zero withdrawal costs and positive injection costs

We assume that injection costs are of the same form as in the main text (e.g. quadratic). Irreversibility of storage decision with positive injection costs amounts to irreversibility in injection costs. In the peak, injection costs are already sunk and hence, all gas is withdrawn regardless of the uncertainty outcome. Thus, aggregate storage sector expected profits is given by:

$$-P_v Q_s - \frac{1}{2} c_s Q_s^{\ 2} + \beta P_p^H Q_s + (1-\beta) P_p^L Q_s$$

Since the storage sector is perfectly competitive, quantity injected in storage is given by the condition of zero marginal expected profit or:

$$-P_v - c_s Q_s + \beta P_p^H + (1-\beta) P_p^L = 0$$

$$\Rightarrow Q_s = \frac{\beta P_p^H + (1-\beta) P_p^L - P_v}{c_s}$$

To prove that Proposition 2.1 still holds with a positive injection cost and zero withdrawal cost, we show that pipeline expected profit is higher under irreversibility of the storage decision than under full reversibility. We proceed in two steps. First, we calculate a lower bound of this increased profitability, by taking equilibrium prices under *irreversibility* as given and assuming storage quantities can be modified *ex post*, according to the peak-valley price differential. That is, we assume in the case of a high peak, end-users can "inject" more gas in the valley and withdraw it in the peak. In the case of a low peak, end-users can "reduce" their injection in the valley so as to withdraw less in the peak. These adjustments are assumed to occur at no extra cost, and they are assumed, in this first step, to have no impact on equilibrium prices. In the second, step we take the effect of such adjustments on equilibrium prices (i.e. we assume full *reversibility* in the storage decision). We find that taking the effect on prices leads to an even higher profitability under irreversibility of storage decision.

Let P_v,P_p^H,P_p^L and Q_s be the equilibrium prices and storage injection/withdrawal under *irreversibility* of storage decision. The resulting pipeline expected profit is:

$$E(\Pi) = \beta\left[P_v Q_v(P_v) + Q_s P_v + P_p^H Q_p^H(P_p^H) - Q_s P_p^H\right] + (1-\beta)\left[P_v Q_v(P_v) + Q_s P_v + P_p^L Q_p^L(P_p^L) - Q_s P_p^L\right]$$

where $Q_v(.)$ and Q_p^i (.) represent end-user demand (for i=H,L). Allowing adjustments in the storage decision, *ex-post*, without any change on equilibrium prices, yields to the following storage injection/withdrawal amounts for i=H,L:

$$Q_s^{i0} = \frac{P_p^i - P_v}{c_s}$$

The resulting expected profit is:

$$\begin{aligned} E(\Pi)^0 &= \beta\left[P_v Q_v(P_v) + Q_s^{H0} P_v + P_p^H Q_p^H(P_p^H) - Q_s^{H0} P_p^H\right] + (1-\beta)\left[P_v Q_v(P_v) + Q_s^{L0} P_v + P_p^L Q_p^L(P_p^L) - Q_s^{L0} P_p^L\right] \\ &= \beta\left[P_v Q_v(P_v) + P_p^H Q_p^H(P_p^H) - \frac{(P_p^H - P_v)^2}{c_s}\right] + (1-\beta)\left[P_v Q_v(P_v) + P_p^L Q_p^L(P_p^L) - \frac{(P_p^L - P_v)^2}{c_s}\right] \end{aligned}$$

Allowing for these adjustment decisions leads to a decrease in expected profits, relative to the irreversibility case:

$$\begin{aligned} E(\Pi) - E(\Pi)^0 &= \beta\left[P_v(Q_s - Q_s^{H0}) - P_p^H(Q_s - Q_s^{H0})\right] + (1-\beta)\left[P_v(Q_s - Q_s^{L0}) - P_p^L(Q_s - Q_s^{L0})\right] \\ &= \beta(P_v - P_p^H)\left[\beta P_p^H + (1-\beta)P_p^L - P_v - P_p^H + P_v\right]/c_s \\ &\quad + (1-\beta)(P_v - P_p^L)\left[\beta P_p^H + (1-\beta)P_p^L - P_v - P_p^L + P_v\right]/c_s \\ &= \frac{\beta(1-\beta)(P_p^H - P_p^L)^2}{c_s} > 0 \end{aligned}$$

Moreover, in the second step of our proof, we show that the above expression is a lower bound. Including the effects of adjusting storage decision on equilibrium prices lead to an even higher decrease in profits relative to the irreversibility case. Let P_v^H*, P_p^H*, P_v^L*, P_p^L*, Q_s^H* and Q_s^L* be the equilibrium prices and storage

$$Q_s^i* = \frac{P_p^i* - P_v^i*}{c_s}$$

injection/withdrawals under this *full reversibility* assumption. Again, we have for i=H,L: The expected pipeline profit is:

$$E(\Pi)^* = \beta\left[P_v^H * Q_v(P_v^H *) + P_p^H Q_p^H(P_p^H *) - \frac{(P_p^H * - P_v^H *)^2}{c_s}\right]$$
$$+ (1-\beta)\left[P_v^L * Q_v(P_v^L *) + P_p^L Q_p^L(P_p^L *) - \frac{(P_p^L * - P_v^L *)^2}{c_s}\right]$$

Now, in the case of high peak demand, adjustments in the storage decision lead to a decrease in the peak price and an increase in the valley price, $P_p^H * < P_p^H$ and $P_v^H * > P_v$. Similarly, in the case of low peak demand, these adjustments lead to an increase in the peak price and a decrease in the valley price, $P_p^L * > P_p^L$ and $P_v^L * > P_v$. Thus, we have:

$$E(\Pi)^0 - E(\Pi)^* > \beta\left[P_v^H * \left(Q_v(P_v) - Q_v(P_v^H *)\right) + Q_p^H(P_p^H *)\left(P_p^H - P_p^H *\right) - \frac{\left(P_p^H * - P_v^H *\right)^2}{c_s} + \frac{\left(P_p^H * - P_v^H *\right)^2}{c_s}\right]$$
$$= (1-\beta)\left[Q_v(P_v^L *)\left(P_v - P_v^L *\right) + P_p^L * \left(Q_p^L(P_p^L) - Q_p^L(P_p^L *)\right) - c_s\left[Q_s^{L0^2} - Q_s^{L0} *^2\right]\right]$$

where:

$$Q_s^{L0} - Q_s^L * = P_p^L - P_v - P_p^L * + P_v^L *$$
$$= -\left[(P_p^L * - P_p^L) + (P_v - P_v^L *)\right] < 0$$

Thus, we have:

$$E(\Pi)^0 - E(\Pi)^* > 0$$
$$\Rightarrow E(\Pi) > E(\Pi)^0 > E(\Pi)^*$$

That is, Proposition 2.1 is robust to our assumptions about the nature of the cost structure of the storage sector. In essence, the irreversibility of the storage decision deprives end users from the flexibility to adjust the storage decision once uncertainty unfolds. This lack of flexibility works to the benefit of the pipeline, as it can more efficiently limit the competitive effect of storage.

Q.E.D.

Appendix 2.B: Proof of the Convexity of Profit Functions in the Certainty case

From the results derived for the certainty case, we note that the pipeline profit function under a long term with seasonal component contract structure is given by:

$$\Pi^{LT-S} = \frac{c_s}{4(s^2-1)}\left[\theta_v(\theta_v s+\theta_p)+\theta_p(\theta_v+s\theta_p)\right]$$

with $s=c_s\gamma+1$. We note that the profit function is quadratic in θ_p with positive coefficients. Thus the profit function is convex in θ_p. Q.E.D

Similarly, the pipeline profit under a short term contract structure in the case of certainty is given by:

$$\Pi^{ST} = \frac{c_s(s\theta_v+\theta_p)}{4s^2-3}\left[\theta_v - \frac{\theta_v s+\theta_p}{s(4s^2-3)}\right] + \frac{1}{4c_s s}\left[c_s\theta_p + \frac{2c_s(\theta_v s+\theta_p)}{4s^2-3}\right]^2$$

The resulting first and second derivatives are given by:

$$\frac{\partial \Pi^{ST}}{\partial \theta_p} = \frac{c_s\theta_v}{4s^2-3} - \frac{2c_s(s\theta_v+\theta_p)}{s\left(4s^2-3\right)^2} + \frac{1}{2c_s s}\left[c_s\theta_p + \frac{2c_s(\theta_v s+\theta_p)}{4s^2-3}\right]\left(c_s + \frac{2c_s}{4s^2-3}\right) > 0$$

$$\frac{\partial^2 \Pi^{ST}}{\partial \theta_p{}^2} = -\frac{2c_s}{s\left(4s^2-3\right)^2} + \frac{c_s}{2s}\left(1+\frac{2}{4s^2-3}\right) > 0$$

Q.E.D.

Appendix 2.C: Derivation of the Solution for the Storage Equilibrium under a Long Term Contract Structure

From our discussion, we know:

$$Q_s^I = \frac{\beta P_p^H - P_v}{c_s\beta} \qquad (1)$$

$$Q_s^{WL} = \frac{P_p^L}{c_s} \qquad (2)$$

An alternative mechanism (equivalent to the one described in the text) is for the pipeline to choose throughput quantity for the peak, Q'_p, and price in the valley, P_v. That is:

$$Q'_p = \theta_p^H - \gamma P_p^H - Q_s^I = \frac{1}{c_s\beta}\left[c_s\beta\theta_p^H - P_p^H\beta(c_s\gamma+1) + P_v\right]$$

$$Q'_p = \theta_p^L - \gamma P_p^L - Q_s^{WL} = \frac{1}{c_s}\left[c_s\theta_p^L - P_p^L(c_s\gamma+1)\right]$$

And the resulting high peak and low peak are:

$$P_p^H = \frac{c_s\beta(\theta_p^H - Q'_p) + P_v}{\beta s} \qquad (3)$$

$$P_p^L = \frac{c_s(\theta_p^L - Q'_p)}{s} \qquad (4)$$

with $s=c_s\gamma+1$. Hence expected peak price is given as:

$$\beta P_p^H + (1-\beta)P_p^L = \frac{c_s(\bar{\theta}_p - Q'_p) + P_v}{s} \qquad (5)$$

where

$$\bar{\theta}_p = \beta\theta_p^H + (1-\beta)\theta_p^L$$

Similarly, valley throughput demand is:

$$\begin{aligned} Q_v' &= \theta_v - \gamma P_v + Q_s^I \\ &= \frac{1}{c_s\beta}\left[c_s\beta\theta_v - P_v r + \beta P_p^H\right] \\ &= \frac{1}{c_s\beta s}\left[c_s\beta(s\theta_v + \theta_p^H) - c_s\beta Q'_p - P_v(sr-1)\right] \qquad (6) \end{aligned}$$

where $r= c_s\gamma\beta+1$.

The maximization problem facing the monopolist is thus:

$$\underset{P_v, Q'_p}{Max}\ \frac{P_v}{c_s\beta s}\left[c_s\beta(s\theta_v + \theta_p^H) - c_s\beta Q'_p - P_v(sr-1)\right] + \frac{Q'_p}{s}\left[c_s(\bar{\theta}_p - Q'_p) + P_v\right]$$

The resulting First Order Conditions (FOC) for valley price and peak quantity are thus:

$$\begin{aligned} &c_s\beta\left[s\theta_v + \theta_p^H\right] - 2(sr-1)P_v = 0 \\ &c_s\bar{\theta}_p - 2c_s Q'_p = 0 \qquad (7) \end{aligned}$$

Solving this system of equations, we have:

$$P_v^{LT} = \frac{c_s \beta}{2(sr-1)}\left[s\theta_v + \theta_p^H\right]$$

We find our solution as a function of valley price. From (7), we find peak throughput demand:

$$Q_p^{*LT} = \frac{\bar{\theta}_p}{2}$$

From (3) and (4), we find high and low peak prices to be:

$$P_p^{HLT} = \frac{1}{2\beta s}\left[c_s \beta\left(2\theta_p^H - \bar{\theta}_p\right) + 2P_v^{LT}\right]$$

$$P_p^{LLT} = \frac{c_s\left(2\theta_p^L - \bar{\theta}_p\right)}{2s}$$

From (5) expected peak price is given as:

$$E(P_p)^{LT} = \frac{1}{2s}\left[c_s \bar{\theta}_p + 2P_v^{LT}\right]$$

From (1) and (2) we find storage injections and withdrawals:

$$Q_s^{ILT} = \frac{1}{2\beta s c_s}\left[c_s \beta\left(2\theta_p^H - \bar{\theta}_p\right) - P_v^{LT} 2(s-1)\right]$$

$$Q_s^{WLLT} = \frac{2\theta_p^L - \bar{\theta}_p}{2s}$$

From (6), we find valley throughput demand to be:

$$Q_v^{*LT} = \frac{s\theta_v + \theta_p^H - \bar{\theta}_p}{2s}$$

Finally, we find expected pipeline profit to be:

$$\begin{aligned} E(\Pi)^{LT} &= P_v^{LT} \cdot Q_v^{*LT} + E(P_p)^{LT} \cdot Q_p^{*LT} \\ &= P_v^{LT} \frac{s\theta_v + \theta_p^H - \bar{\theta}_p}{2s} + \frac{\bar{\theta}_p}{4s}\left[c_s \bar{\theta}_p + 2P_v^{LT}\right] \end{aligned}$$

Appendix 2.D: Derivation of the Solution for the Storage Equilibrium under a Short Term Contract Structure

Let us first determine valley throughput demand as a function of valley price. We have:

$$Q'_v = \theta_v - \gamma P_v + Q_s^I$$
$$= \theta_v - \gamma P_v + \frac{\beta P_p^H - P_v}{c_s \beta}$$

From our discussion, we have

$$P_p^{HST} = \frac{c_s \beta \theta_p^H + P_v^{ST}}{2\beta s}$$

Hence, valley throughput demand is thus:

$$Q_v^{ST} = \frac{1}{2c_s\beta}\left[c_s\beta(2s\theta_v + \theta_p^H) - (2sr-1)P_v^{ST}\right]$$

The pipeline faces the following problem:

$$\underset{P_v}{Max}\, P_v Q_v + \beta \Pi_p^H(P_v) + (1-\beta)\Pi_p^L(P_v)$$
$$\Rightarrow \underset{P_v}{Max} \frac{P_v}{2c_s\beta s}\left[c_s\beta(2s\theta_v + \theta_p^H) - P_v(2sr-1)\right] + \frac{\beta\left[c_s\beta\theta_p^H + P_v\right]^2}{4c_s\beta^2 s} + \frac{(1-\beta)c_s\theta_p^{L^2}}{4s}$$

The First Order Condition (FOC) is thus:

$$2c_s\beta(s\theta_v + \theta_p^H) - P_v[4sr-3] = 0$$
$$\Rightarrow P_v^{ST} = \frac{c_s\beta}{4sr-3}\left[2(s\theta_v + \theta_p^H)\right]$$

Finally, the pipeline expected profits under this short term structure is:

$$E(\Pi)^{ST} = \frac{P_v^{ST}}{2c_s\beta s}\left[c_s\beta(2s\theta_v + \theta_p^H) - P_v^{ST}(2sr-1)\right] + \frac{\beta\left[c_s\beta\theta_p^H + P_v^{ST}\right]^2}{4c_s\beta^2 s} + \frac{(1-\beta)c_s\theta_p^{L^2}}{4s}$$
$$= \frac{P_v^{ST}}{2c_s\beta s}\left[c_s\beta(2s\theta_v + \theta_p^H) - P_v^{ST}(2sr-2+1)\right] + \frac{c_s^2\beta^2\theta_p^{H^2} + 2c_s\theta_p^H\beta P_v^{ST} + P_v^{ST^2}}{4c_s\beta s}$$
$$+ \frac{(1-\beta)c_s\theta_p^{L^2}}{4s}$$
$$= \frac{P_v^{ST}}{c_s\beta s}\left[c_s\beta(s\theta_v + \theta_p^H) - P_v^{ST}(sr-1)\right] + \frac{c_s^2\beta^2\theta_p^{H^2} - P_v^{ST^2}}{4c_s\beta s} + \frac{(1-\beta)c_s\theta_p^{L^2}}{4s}$$

Appendix 2.E: Proof of Proposition 2.3

We first prove that expected profits under both contract structures are convex with respect to θ_p^H. We note that[32]:

$$\frac{\partial P_v^{LT}}{\partial \theta_p^H} = \frac{c_s \beta}{l} > 0$$

$$\frac{\partial P_v^{ST}}{\partial \theta_p^H} = \frac{2c_s \beta}{m} > 0$$

where:

$$l = 2(sr - 1)$$

$$m = 4sr - 3$$

Now,

$$\frac{\partial E(\Pi)^{LT}}{\partial \theta_p^H} = \frac{1}{2s}\frac{\partial P_v^{LT}}{\partial \theta_p^H}\left[s\theta_v + \theta_p^H - \bar{\theta}_p\right] + \frac{1}{2s}\left[P_v^{LT} + \frac{\partial P_v^{LT}}{\partial \theta_p^H}\bar{\theta}_p\right]$$

$$= \frac{1}{2s}\left[\frac{\partial P_v^{LT}}{\partial \theta_p^H}\left(s\theta_v + \theta_p^H\right) + P_v^{LT}\right] > 0$$

The second derivative is:

$$\frac{\partial^2 E(\Pi)^{LT}}{\partial \theta_p^{H\,2}} = \frac{1}{2s}\left[2\frac{\partial P_v^{ST}}{\partial \theta_p^H}\right]$$

$$= \frac{c_s \beta}{sl} > 0$$

Hence, pipeline expected profit under a long term structure is indeed convex.

Similarly, under a short term contract structure, we have[33]:

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[32] Here, we take the derivative with respect to θ_p^H while keeping average θ_p constant.

[33] We first rewrite the expected pipeline profit under a short term structure by substituting θ_p^L as a function of θ_p^H and average θ_p. We then take the derivative with respect to θ_p^H.

$$\frac{\partial E(\Pi)^{ST}}{\partial \theta_p^H} = \frac{1}{\beta s c_s}\frac{\partial P_v^{ST}}{\partial \theta_p^H}\left[c_s\beta(s\theta_v + \theta_p^H) - 2(sr-1)P_v^{ST}\right] + \frac{P_v^{ST}}{s} + \frac{1}{2sc_s\beta}\left[c_s{}^2\beta^2\theta_p^H - \frac{\partial P_v^{ST}}{\partial \theta_p^H}P_v^{ST}\right]$$

$$-\frac{c_s\beta}{2s(1-\beta)}(\bar{\theta}_p - \beta\theta_p^H)$$

$$= \frac{1}{s}\left[(s\theta_v + \theta_p^H)\frac{\partial P_v^{ST}}{\partial \theta_p^H} + P_v^{ST}\right] - \frac{1}{2\beta s c_s}\frac{\partial P_v^{ST}}{\partial \theta_p^H}P_v^{ST}(4sr-3) + \frac{c_s\beta(\theta_p^H - \bar{\theta}_p)}{2s(1-\beta)}$$

$$= \frac{1}{ms}\left[2c_s\beta(s\theta_v + \theta_p^H)\right] + \frac{c_s\beta(\theta_p^H - \bar{\theta}_p)}{2s(1-\beta)}$$

$$> 0$$

Taking the second derivative, we find:

$$\frac{\partial^2 E(\Pi)^{ST}}{\partial \theta_p^{H\,2}} = \frac{2c_s\beta}{sm} + \frac{c_s\beta}{2s(1-\beta)} > 0$$

Thus, expected pipeline profit under a short term contract structure is also convex in θ_p^H. Finally, the difference in the second derivative is:

$$\frac{\partial^2 E(\Pi)^{ST}}{\partial \theta_p^{H\,2}} - \frac{\partial^2 E(\Pi)^{LT}}{\partial \theta_p^{H\,2}} = \frac{c_s\beta}{2s(1-\beta)ml}\left[2(1-\beta)(2l-m) + ml\right]$$

$$= \frac{c_s\beta}{s(1-\beta)ml}\left[(sr-1)(4sr-3) - (1-\beta)\right]$$

$$> 0$$

This shows the condition in the proposition to be true.

Q.E.D.

Appendix 2.F: Derivation of the Solution for the Storage Equilibrium under a Long Term Contract Structure and No Infrastructure in Place

The derivation of this solution follows closely the one in Appendix 2.C. Let K be the investment capacity. In equilibrium, capacity is binding in the peak. From Eq (3) and (4) in Appendix 2.C, we have:

$$P_p^H = \frac{c_s\beta(\theta_p^H - K) + P_v}{\beta s} \qquad (1)$$

$$P_p^L = \frac{c_s(\theta_p^L - K)}{s} \qquad (2)$$

Expected peak price is given by:

$$\beta P_p^H + (1-\beta)P_p^L = \frac{c_s(\bar{\theta}_p - K) + P_v}{s} \qquad (3)$$

From Eq (6) in Appendix 2.C, valley throughput demand is:

$$Q'_v = \frac{1}{c_s\beta s}\left[c_s\beta(s\theta_v + \theta_p^H) - c_s\beta K - P_v(sr-1)\right] \qquad (4)$$

The maximization problem facing the monopolist is thus:

$$\underset{P_v,K}{Max}\frac{P_v}{c_s\beta s}\left[c_s\beta(s\theta_v + \theta_p^H) - c_s\beta K - P_v(sr-1)\right] + \frac{K}{s}\left[c_s(\bar{\theta}_p - K) + P_v\right] - kK$$

The resulting First Order Conditions for valley price and investment level are thus:

$$c_s\beta\left[s\theta_v + \theta_p^H\right] - 2(sr-1)P_v = 0$$

$$\frac{c_s}{s}(\bar{\theta}_p - 2K) - k = 0 \qquad (5)$$

Solving this system of equations, yields:

$$P_v^{LT} = \frac{c_s\beta(s\theta_v + \theta_p^H)}{2(sr-1)}$$

Again, we find our solution as a function of valley price. From (5), we find investment level:

$$K_p^{LT} = \frac{\bar{\theta}_p}{2} - \frac{sk}{2c_s}$$

From (1) and (2) we find peak prices:

$$P_p^{HLT} = \frac{1}{\beta s}\left[c_s\beta\left(2\theta_p^H - \bar{\theta}_p\right) + 2P_v^{LT}\right] + \frac{k}{2}$$
$$P_p^{LLT} = \frac{c_s\left(2\theta_p^L - \bar{\theta}_p\right)}{2s} + \frac{k}{2}$$

From (3) expected peak price is given as:

$$E(P_p)^{LT} = \frac{1}{2s}\left[c_s\bar{\theta}_p + 2P_v^{LT}\right] + \frac{k}{2}$$

Storage injection and withdrawals are:

$$Q_s^{ILT} = \frac{1}{2\beta s c_s}\left[c_s\beta\left(2\theta_p^H - \bar{\theta}_p\right) - 2P_v^{LT}(s-1)\right] + \frac{k}{2c_s}$$
$$Q_s^{WLLT} = \frac{\left(2\theta_p^L - \bar{\theta}_p\right)}{2s} + \frac{k}{2c_s}$$

From (4), we find valley throughput demand to be:

$$Q_v^{*LT} = \frac{1}{\beta s c_s}\left[c_s\beta\left(s\theta_v + \theta_p^H - \bar{\theta}_p\right) - P_v^{LT}(sr-1)\right] + \frac{k}{2c_s}$$
$$= \frac{1}{2s}\left[s\theta_v + \theta_p^H - \bar{\theta}_p\right] + \frac{k}{2c_s}$$

Expected pipeline profit is:

$$E(\Pi)^{LT} = P_v^{LT} \cdot Q_v^{*LT} + E(P_p)^{LT} \cdot K^{LT} - kK^{LT}$$
$$= \frac{P_v^{LT}}{2s}\left[s\theta_v + \theta_p^H\right] + \frac{c_s\bar{\theta}_p^{\,2}}{4s} - \frac{k\bar{\theta}_p}{2} + \frac{sk^2}{4c_s}$$

Finally, in order to guarantee a partial withdrawal of gas in storage in the case of low peak demand, the following condition must hold, following the discussion in the third part of the chapter:

$$P_v^{LT} < \beta(P_p^{HLT} - P_p^{LLT})$$

$$\frac{c_s\beta(s\theta_v + \theta_p^H)}{2(sr-1)} < \frac{1}{2s}\left[c_s\beta(2\theta_p^H - \bar{\theta}_p) + 2P_v\right] - \frac{c_s\beta}{2s}(2\theta_p^L - \bar{\theta}_p)$$

$$\frac{c_s\beta(s\theta_v + \theta_p^H)}{2(sr-1)} < \frac{c_s\beta}{s}(\theta_p^H - \theta_p^L) + \frac{c_s\beta(s\theta_v + \theta_p^H)}{2s(sr-1)}$$

$$\Rightarrow (s\theta_v + \theta_p^H)(s-1) < (\theta_p^H - \theta_p^L)$$

Appendix 2.G: Proof of Proposition 2.5

We have:

$$K^{LT} - K^{ST} = \frac{\bar{\theta}_p}{2} - \frac{sk}{2c_s} - \frac{\theta_p^H}{2} + \frac{ks}{2c_s\beta}$$

$$= \frac{(1-\beta)}{2}\left[\frac{sk}{c_s\beta} - (\theta_p^H - \theta_p^L)\right]$$

Thus, investments under a short term contract are higher if

$$\theta_p^H - \theta_p^L > \frac{sk}{c_s\beta}$$

Q.E.D.

Appendix 2.H: Proof of Proposition 2.6

From the equilibrium solutions, we have:

$$E(\Pi)^{ST} - E(\Pi)^{LT} = \frac{P_v^{ST}}{2s}\left[s\theta_v + \theta_p^H\right] + \frac{c_s}{4s}\left[(1-\beta)\theta_p^{L^2} + \beta\theta_p^{H^2}\right] - \frac{\theta_p^H k}{2} + \frac{sk^2}{4c_s\beta}$$

$$- \frac{P_v^{LT}}{2s}\left[s\theta_v + \theta_p^H\right] - \frac{c_s\bar{\theta}_p^{\ 2}}{4s} + \frac{k\bar{\theta}_p}{2} - \frac{sk^2}{4c_s}$$

$$= \frac{1}{2s}\left[s\theta_v + \theta_p^H\right]\left[P_v^{ST} - P_v^{LT}\right] + \frac{c_s}{4s}\beta(1-\beta)\left(\theta_p^H - \theta_p^L\right)^2$$

$$- \frac{k(1-\beta)}{2}\left(\theta_p^H - \theta_p^L\right) + \frac{sk^2}{4c_s\beta}(1-\beta)$$

Now, from the equilibrium solutions, the following holds:

$$P_v^{ST} = P_v^{LT}$$

Thus, expected profit difference is:

$$
\begin{aligned}
E(\Pi)^{ST} - E(\Pi)^{LT} &= \frac{1-\beta}{2}\left[\frac{c_s\beta}{2s}\left(\theta_p^H - \theta_p^L\right)^2 - k\left(\theta_p^H - \theta_p^L\right) + \frac{sk^2}{2c_s\beta}\right] \\
&= \frac{(1-\beta)c_s\beta}{4s}\left[\left(\theta_p^H - \theta_p^L\right)^2 - 2\frac{sk}{c_s\beta}\left(\theta_p^H - \theta_p^L\right) + \left(\frac{sk}{c_s\beta}\right)^2\right] \\
&= \frac{(1-\beta)c_s\beta}{4s}\left[\left(\theta_p^H - \theta_p^L\right) - \frac{sk}{c_s\beta}\right]^2 > 0
\end{aligned}
$$

Q.E.D.

Chapter 3:

Risk, Contracts, Infrastructure and their Relationship to Capacity Rights and Pipeline Investments

3.1. Introduction

The previous chapters showed that in the presence of storage, the ability of a monopolist pipeline to extract monopoly rents greatly depends on the contracting regime. Furthermore, they showed how contract structure also affects the incentives for pipeline investment by a monopolist. However, the analysis of the investment decision assumed a perfect world (except for the monopolist position of the pipeline): perfect information sharing and a perfect financial market (with completely diversified investors). These are, of course, unrealistic assumptions. First, end users (in this case, local distribution companies (LDCs) and electric companies for example) know more about their natural gas demand than pipeline companies. For pipelines to make efficient investments, it is

important that this information be shared with them. Second, there are significant differences in the ability of pipeline companies and end users to bear the risks involved in developing gas pipeline projects. These characteristics, as many other, could potentially lead to the failure to develop natural gas pipeline projects that are economically attractive from a social point of view, but unattractive to one of the parties because of the inability to solve the above problems. Different contracting mechanisms can effectively alleviate these problems by sharing risks and returns in an efficient manner and by providing the right incentives for information sharing and efficient behavior by all parties.

This final chapter explores in greater detail the role of contracts in the development of natural gas pipeline projects. The starting point, as it has been throughout the dissertation, is a well functioning capacity rights market (which will be defined later). This chapter aims at evaluating different contract structures with respect to the effectiveness with which they alleviate the characteristics described above. Furthermore, the chapter also explores how the effectiveness of the different contract structures changes as a function of the physical infrastructure in place at the time of the investment. In this sense, contract structure and infrastructure should be seen as complementary. The objective is to evaluate the desirability, from the perspective of all parties, of different contracting mechanisms as a function of the infrastructure in place.

The analysis adopts a Paretian definition of desirability. That is, contract A is more desirable than contract B, from the perspective of all parties, if contract A improves the position of at least one party without making any of the other parties involved worse off. Thus, making a contract more desirable is a non-zero-sum process in which none of the parties lose and at least one can gain. However, it is important to note that the analysis assumes that all decisions are made by private, as opposed to government, actors. As such, there is no guarantee that a Pareto efficient contract among *private* actors with market power will necessarily lead to an increase in *social* welfare. In this sense, the chapter also focuses on allocative economic efficiency as a second dimension to the desirability of a contract, making regulation an important tenant of the analysis. The analysis concentrates on analyzing Pareto efficient contracting schemes *given* a regulatory scheme that aims at allocative efficiency.

This final chapter is organized in three sections. The next section defines a well functioning capacity rights market. It discusses its necessary conditions as well as the information content of the capacity price and the relationship between the different capacity markets (i.e. firm versus interruptible markets, long versus short term markets). The third section identifies the issues that need to be considered when designing desirable contracts, as defined above. The fourth section discusses the desirability of different contract structures as a function of infrastructure in place. The chapter analyses three infrastructure scenarios: (i) a monopolist pipeline, (ii) a monopolist pipeline in the context of storage, and (iii) a pipeline that is part of a well integrated pipeline grid system. The first two scenarios directly relate to the first two chapters of this dissertation and our analysis will incorporate the results of these chapters. We can think of the first scenario as the case of infant markets such as the Southern Cone market, and the third scenario as the case of a mature and integrated market such as the United States.

3.2. A Well Functioning Capacity Rights Market

This second section characterizes a well functioning capacity rights market and the relationship between the different capacity markets: short term, long term and interruptible markets. The section also describes the role of capacity price as a signal for infrastructure investment.

3.2.1. Characteristics of Capacity Rights Market

As described in the introduction of the dissertation, the restructuring of the natural gas industry entails the vertical separation of the different components: production, transportation and distribution. This restructuring allows end users to compete for gas at the well head, but they must now purchase a transportation service to deliver gas to the burner tip. In this new industry structure, it is only natural to think of access to the pipeline as a separate and complementary asset to gas. A capacity rights market is based on the assumption that such an asset is tradable. The holder of such an asset owns the right to ship volumes up to the capacity limit over the specified segment on which the

right is held. Under such market, the ownership and control of transportation capacity is indeed decentralized among the many holders, each of which makes their own choices as to its use or allocation.

Pipelines issue transportation rights, which are sold on a primary market to the highest bidder. Because many end users (LDCs, electric generators and large industrial users) need transportation rights for their gas supplies, bidding for these rights in the primary market is competitive. Even marketers might participate in this market so that they can purchase gas and transportation services and sell them as a rebundled good to end users. Moreover, the key to a well functioning capacity rights market is a secondary market. Trading in such secondary market would not only ensure that pipeline capacity goes to the end user that values it the most, but also would considerably hamper the ability of a pipeline to price discriminate among different shippers. Two important conditions must be met if this secondary market is to effectively price capacity:

1. *Capacity Release*: Each holder of a capacity right must be able to resell it. This condition has been introduced in Order 636 in the US market, although there is a regulated cap on the price at which this right can be released. In FERC's Notice of Proposed Rulemaking ("NOPR") of July 1998, FERC is seeking comments for the elimination of this price cap. Most analysts expect the removal of the cap in the near future.

2. *Flexible receipt and delivery points:* The ability to receive and deliver gas at different points allows a greater standardization of capacity rights. This flexibility allows shippers to convert transportation that is useful to one shipper into transportation useful to another. This flexibility increases the liquidity of secondary capacity markets and is thus critical for a well functioning capacity rights market. It is important to note that the physics of pipeline transportation allows for this flexibility. To maintain pressure inside a pipeline constant, a determined gas volume is needed inside at all times. Gas is not really transported along the pipeline. Rather, an amount of gas is injected at one end and the same

amount is withdrawn at another thereby maintaining pressure constant[34]. Injection and withdrawals points can thus change without affecting pipeline pressure as long as they belong to the same pipeline system.

Under a capacity rights market, pipelines recover their investment and other fixed costs through capacity sales in the primary market. Of course a pipeline may sell capacity rights forward, in which case the original holder of the right agrees to pay the agreed price at some point in the future even if the right has been sold on the secondary market[35]. Any variable costs incurred in the injection and withdrawal of gas are recovered through a transmission rate. Currently in the US and in most natural gas markets, this rate is regulated using conventional regulatory ratemaking, as pipelines are considered natural monopolies. This chapter will have very little to say about transmission rates. It will assume there is a mechanism (administrative or market determined) that allows the full recovery of variable costs, and concentrate on the incentives that capacity rights markets provide to pipeline investment. To understand the incentives for pipeline investment, we must first understand the relationship between the different capacity rights markets and the role of contracts in pipeline investments.

3.2.2. Relationships among the Different Capacity Rights Markets

In the NOPR issued in July 1998, FERC proposes different approaches to the regulation of the short term market, defined as contracts of less than one year, and the long term market for transportation services on the grounds that the two markets are significantly different. Moreover, FERC also seeks comments on the regulation of firm and interruptible capacity rights. Understanding the interaction among these markets is important as it will affect the pipeline incentives for (and end users willingness to embrace) additional capacity. The chapter argues that long term and short term contract should *not* be seen as different in a well functioning capacity rights market; that in fact

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[34] This is somewhat of a simplification as friction inside pipelines makes the use of compressors necessary. Thus injections might exceed withdrawals.

[35] Tabors and Wilson (1999) also look at a similar arrangement for capacity rights in the electricity industry.

they are very much part integrated. Also, the chapter argues that pipelines are indifferent with regard to interruptible rights, as these have no bearing on the primary market in which pipelines operate. In a well functioning capacity rights market interruptible rights are traded among shippers only.

3.2.2.1. The Relationship of Short Term Markets and Long Term Markets

FERC's argument for the difference between long and short term markets lies on the number of players that can sell capacity in both markets. FERC assumes that long term markets are the primary markets in which a pipeline sells capacity rights, and as a result can exploit its monopolistic capacity. In contrast, short term markets, through capacity releases into a secondary capacity market, are competitive as shippers can choose between numerous releasing shippers and the pipeline itself. It seems, according to FERC's distinction, that we must understand the equilibria in both markets to determine a pipeline's incentives for investment in capacity addition. However, the chapter argues that both markets are closely integrated. A pipeline cannot treat one market separately from the other. Thus, there is a *unique* equilibrium that embraces both markets determined by the total number of rights issued by the pipeline (both in the short and long term contracts). In other words, we must look at this equilibrium in terms of total number of rights issued to understand the incentives for investment.

Understanding this argument requires separating the two issues at hand. First, the dispersion of rights ownership in the short term market (resulting from capacity release) guarantees a competitive and efficient exchange of rights in that it leads to the allocation of rights to those end users that value it the most. The number of rights allocated is equal the number of rights issued in the primary market (short term and long term) by the pipeline. In other words, the short term market is efficient *given the total number of rights issued by the pipeline.* Second, what are the incentives for the pipeline to issue new rights in the short term market after the assignment of rights in the long term market? Evaluating this question is critical for understanding the incentives for pipeline investment.

Chapters one and two of the dissertation give us insight to answer this question. The real issue is whether a monopolist pipeline can credibly commit in the short term markets to the agreements incurred in the long term markets. End users willingness to pay for capacity rights in the long term markets depends on their expectations of future prices in the short term markets. Expected new issues in the short term markets will reduce the value of those issued in the long term markets. Correspondingly, end users will be willing to pay less for capacity rights in the long term markets if they expect the pipeline to issue new rights in the short term market. In other words, it is this expectation about the pipeline behavior in the short term market that effectively links the two together. The two markets cannot be treated independently.

To understand whether it is in the monopolist pipeline interests to commit to not issue new rights in the short term market, take the case with no storage capacity available analyzed in chapters one and two[36]. In the case of perfect certainty (chapter one), the monopolist pipeline is indifferent between committing and not committing. If the number of rights issued in the long term market is the monopolistic quantity (i.e. quantity that maximizes monopolist profits), the pipeline cannot gain by issuing more rights in the short term market. If it issues more rights, end users will know this[37] and will incorporate it into the price paid in the long term market. Clearly, the pipeline will not maximize revenues by doing so. By the same token, if the pipeline does not commit, then it will issue the monopolistic quantity of rights in the short term market. The pipeline maximizes profits by issuing the monopolistic amount of rights; it is indifferent whether it issues them in the short term or long term markets or a combination of both.

In contrast, commitment plays an important role in the case of uncertainty, as analyzed in the second chapter. End users must incorporate their expectations about the

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[36] We neglect any considerations about seasonal demand as well.

[37] The model presented in the first two chapters contains two periods which is of course an incorrect assumption. Real life can be incorporated into the model through an infinite game in which the pipeline loses all credibility if it deviates from the agreement incurred in the long term market. In equilibrium, the pipeline will always comply with its agreement. In this infinite game models reputation becomes a crucial element.

number of new rights issued once uncertainty unfolds. If the pipeline cannot credibly commit not to issue new rights, the capacity rights market will be effectively comprised of a series of short term markets. As we saw in chapter two, the pipeline is better off not committing when uncertainty is large. This is so because the value of the flexibility to adjust the number of capacity rights once uncertainty unfolds is big for large uncertainties.

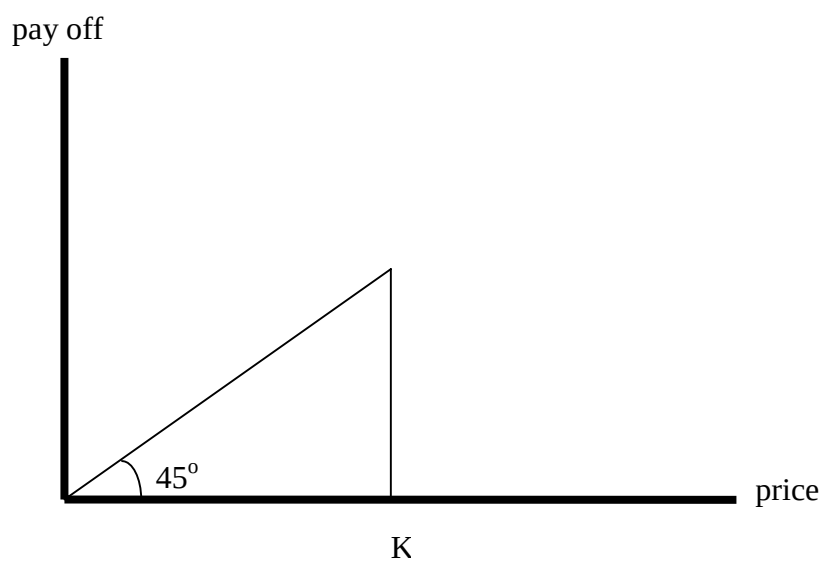
In sum, short term and long term markets are *not* different; they are in fact integrated. A monopolist pipeline cannot treat one separately from the other. The core of the problem, from the perspective of investment decisions, is to understand the incentives for issuing rights in the primary capacity market, both in the short term and in the long term. The competitive and efficient exchange that occurs in the short term market as a result of capacity release has no impact on the incentives for issuing rights in the primary market. It only guarantees that capacity will be allocated to those end users who value capacity the most.

3.2.2.2. The Relationship between Firm and Interruptible Rights Markets

Holders of firm transportation rights own the right to ship volumes up to the capacity limit at any time over the specified segment on which the right is held. In contrast, holders of interruptible transportation may be denied access to the pipeline system in the event of high demand as firm transportation rights holders have priority over them. Firm service is usually purchased to ensure reliability in the transportation service. Demand for interruptible service arose before the restructuring of the industry and the introduction of secondary markets of capacity rights. Pipelines supplied this interruptible service so as to increase the level of throughput when those end users with firm contracts did not make full use of them. End users with access to alternative sources of energy when transportation services were interrupted purchased this service. For example, electric generators with access to fuel oil supply do not require the reliability that a firm contract entails, and could thus reduce costs by purchasing the less expensive interruptible service.

With a well functioning capacity rights market, the pipeline should not sell interruptible service anymore. As noted earlier, the pipeline sells capacity rights in the primary market, which are traded in a competitive secondary market. Trading in the secondary market guarantees that *all* the rights issued by the pipeline get allocated efficiently at a positive price, and thus these rights can be considered as firm in nature. In other words, the pipeline does not have the flexibility to issue interruptible rights since a competitive secondary market for firm rights guarantees that they will all be utilized. Changes in demand and supply conditions will be reflected in the secondary market price for firm rights. However, interruptible rights may still exist in the context of capacity rights markets. These rights will be traded *exclusively among shippers*. For example, a LDC holding a firm right may release it to an electric generator as an interruptible right stipulating that under certain demand conditions the right will revert back to the LDC. Such callable release of the firm right by the LDC can be viewed as a financial option, with the underlying asset being a firm right. The payoffs to the electric generator is illustrated in the figure below:

Figure 3.1: The relationship between Firm and Interruptible Rights



K represents the threshold firm price at which the right reverts back to the LDC. For firm prices below K, the value of the interruptible right to the electric generator is the

firm price because the generator can sell the interruptible right in the capacity rights market. Because this interruptible right has all the properties of a firm right, their price should be the same. For prices above K, the value to the generator is zero as the right has reverted back to the LDC. The price of this interruptible service can thus be determined from the above payoff structure using standard option pricing methodologies. Since this price is determined in the secondary market, the pipeline is indifferent with respect to it. In the financial economics jargon, interruptible rights are redundant in that they do not span or complete the market space. They do not provide additional information about demand and supply conditions that are not already engrained in capacity rights markets for firm rights.

3.2.3. The Role of Contracts in Pipeline Investment

From above, it is the price of firm transportation rights that represents a signal for investments in infrastructure (storage and new pipeline capacity). Investments in storage will be determined by the difference between prices in the peak period (heating season) and the off peak period (non-heating session). Investments will occur as long as the price differential exceeds the marginal cost of storage investment. Although storage plays an important role in the natural gas industry, the chapter will not expand on the issues that need to be considered when evaluating storage investments. Much of what the chapter has to say about pipeline investments does indeed apply to storage investments. The emphasis will thus be on the capacity rights market provides a signal for pipeline investments.

Pipeline companies recover their investment costs through their activities in the primary market for firm capacity rights (both in the short term and long term markets). As noted above, transactions in the secondary markets (which include interruptible rights) have no bearing on the pipeline company recovery of investment costs. Pipeline investments are characterized by large capital outlays, long lead times to project completion and long economic life of the project. As such, these projects are subject to substantial risks. The questions that arise thus are twofold. (i) Is there already a capacity rights market whose price could guide pipeline investments? If this is not the case (as in

infant markets with scant infrastructure), the execution of a pipeline investment will depend on the contractual structure among the different parties. (ii) Even if there is a price for capacity rights, how good of an investment signal is it? Will investment be carried out? Will it be socially efficient? Even if the price signal is correct, differences in the ability of the parties to bear the risks involved might lead to inefficient investment levels. At an extreme, it can lead to the failure to develop the investment project altogether as it would be unattractive to the pipeline because of uncertainties over sharing project risks and returns. Again, the contractual structure is key to the sharing of risk and returns, and thus to the development of pipeline projects.

The remainder of the paper will concentrate on efficient contracting structures for the development of pipeline projects. It will concentrate on three parties: the pipeline company making the investment, electric generation companies, large industrial companies and local distribution companies (LDCs). It will assume that electric generators participate in a competitive wholesale electricity market, which includes a futures market for electricity. LDCs are assumed to represent residential, commercial and small industrial customers. These are captive customers with no direct access to capacity rights markets. LDCs are assumed to be regulated in providing distribution services to its captive customers.

3.3. Contract Features

In general, contracts have different features. Among the most important are[38]:

1. How they allocate investment-costs, market-price and country-macro-political risks.
2. The extent to which they introduce contracting strains, that is, risks of nonperformance by one or more parties.
3. The incentives they create for exploitation of asymmetries in information.

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[38] Charles Blitzer, Donald Lessard and James Paddock (1984) look at similar issues in the context of oil development projects.

From the viewpoint of the pipeline company, the desirability of a particular contract depends among other things, the extent to which it is exposed to market and country risks, its knowledge about potential demand, and the ability to enforce the performance of contracts by the other parties. These circumstances will in turn determine the comparative advantage of pipelines in relation to the other players in assuming various responsibilities and risks, and thus, they will determine the pipeline's incentives for investment. Understanding such circumstances is key in negotiating an efficient contract.

To understand how risk allocation can contribute to a Pareto efficient contract, it is important to understand how parties may trade off a particular risk so that it is borne by the party having a comparative advantage in bearing that risk. For instance, the pipeline could already be over exposed to market risk, and hence at a comparative disadvantage in bearing it relative to an electric generator. Both parties can improve their contractual gains by distributing this risk according to their ability to bear it. By the same token, all parties benefit by reducing contracting risks. Contracts are incomplete in nature. It is impossible to determine contractual responsibilities for all possible states of nature. In some states of nature, some parties might benefit from unilaterally deviating from the contractual agreements. The other parties, recognizing this possibility will demand extra compensation, reducing the potential benefits of the project. It is thus in the best interest of all parties to design a contractual agreement that is both enforceable and that all parties involved will perform. Finally, information asymmetries may lead to inefficient outcomes and thus reduce the potential benefits of the project. Consequently, all parties can gain more by designing mechanisms for information sharing. Similarly, contracts must be designed so that they prevent a party from abusing its dominant position once the pipeline is operational. In the following paragraphs, each of these dimensions will be discussed separately. However, we must recognize that a choice in one dimension may constraint choices in the others.

3.3.1. Risk Allocation and Contracting Efficiency

Throughout this discussion, it is important to remember that risk is not necessarily bad. The least risky projects are not necessarily the better ones, nor are the most risky projects the least attractive. Although risk may clearly reduce the attractiveness of a project, its undertaking will depend on how well risk is managed and allocated among the different parties involved. As argued before, there are benefits in allocating risks as a function of the parties' different ability to bear risks. Comparative advantage in risk bearing goes against the key assumption underlying CAPM or other equilibrium based models: that investors hold *completely* diversified portfolios. In such an idealized world, the return of a project will be based on the project's contribution to systematic risk, the risk which is not diversifiable. Following Lessard (1996), this deviation from CAPM can arise for three reasons: "(1) information is not equally available to all investors; (2) investors may have different degrees of influence over outcomes, and (3) investors may differ in their ability to diversify risks, largely as a result of reasons (1) or (2) above."

Efficient contracts must thus understand the extent of these reasons, and must structure the participation of the various players in the project so as to give those with a comparative advantage in bearing a particular risk a larger exposure to that risk. A party with a comparative advantage will place a higher value on that risk and thus will be willing to pay more for it than a party with no comparative advantage[39]. This comparative advantage depends on how large an exposure each party has on a particular risk and his ability to diversify it. The following paragraphs discuss the different types of risk involved in pipeline projects and the ability of the different players to bear them. We can identify three sources of risk: (i) market-price risk, (ii) investment cost risk, and (iii) country-macro-political risks (relevant when considering projects offshore).

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[39] Alternatively, a party with a comparative ability to diversify a particular risk should *not* be given an extra benefit (in terms of return) to hold that risk. In contrast, a party with no ability to diversify that risk should needs a large incentive in terms of return to hold it.

3.3.1.1. Market-Price Risk

This risk is associated with the variability in the demand (and consequently in price) that the pipeline intends to service. There are two components to this risk: the first associated with overall demand and prices and affecting all sectors of the economy, and the second associated with the specific demand and price of natural gas. If financial markets were complete, this risk could be fully diversifiable by, for example, issuing bonds whose payoffs are linked to the price of capacity rights. In such an idealized world, this risk could be transferred to fully diversified investors, and no party should have a comparative advantage in bearing this risk. The price of this risk would be directly linked to the contribution of this risk to the overall risk of the fully diversified investor. Financial markets, however, are not complete and the different parties have comparative advantages in bearing this risk. Depending on the risk allocation profile resulting from the contracting arrangements, the different parties will require different risk premium in their discount factors when evaluating the different contracts.

In general, pipeline companies can bear some of this risk. There is no world market for natural gas[40], the US market behaves very independently from the European market or the Southern Cone market. Pipeline companies are usually transnational in nature (Enron, British Gas, Tenneco, Nova, etc)[41]. Participation in several regional markets offers pipelines the ability to put "their eggs in several baskets". It is such diversification that allows the pipeline to the ability to bear some of this risk. As such bearing part of these risks should not lead to an increase in the required expected return of the pipeline company. In contrast, pipeline companies that are overly exposed to one particular region have no comparative advantage in bearing market risk when considering investments in that region. As such, bearing this risk should lead to an increase in the required expected return, as an incentive for the pipeline to bear it. The risk profile of

[40] There is a small trade in LNG, but it can hardly be thought as the integrating factor of all markets.

[41] This can be interpreted as a general equilibrium solution. Companies can be thought of as invest abroad for two reasons. First, economies of scope resulting from investing in various markets add value to the company. Second, diversification by investing in various markets also allows more efficient risk management by these companies.

future cash flows for the pipeline depends on the type of contracts. The shorter the length of contracts, the more the pipeline bears this risk. At one extreme, an infinitely long term contract (e.g. selling the pipeline to end users) completely shifts the risk to end users. At the other extreme, an infinitesimally short contract shifts the risk to the pipeline. An efficient contract is between the two extremes and depends on the ability of end users to bear this risk.

Electric generation companies have mechanisms to hedge this risk, and should thus bear as much of this risk as it is comparatively advantageous for them to do so. The electric industry is being restructured around the world introducing competition at the generation level leading to the emergence of spot and futures electricity markets. Precisely, the electricity futures market allows electric generators to hedge market-price risk. Indeed, a long term contract with the pipeline would shift this risk to the electric generator, who in turn can hedge it by selling electricity in the futures market. Of course, the maturities of the long term contract and the futures contract will have to match for a perfect hedge. The length of available electric futures contracts will thus limit the extent to which this risk is transferred to and fully hedged by the electric generation companies. There is no possibility for electric generators to hedge or transfer any residual risks (i.e. for example, risks resulting from futures contracts having a shorter maturity than long term contracts with the pipeline). In other words, when evaluating long term contracts with the pipeline, electric generators should not expect a risk premium in discounting the portion of the contract that can be fully hedged through the electricity futures market. In contrast, the generators should require a risk premium for the portion of the contract that cannot be hedged. The key determinants for this risk premium will be the importance of pipeline capacity right price per unit of electricity generated, and the correlation between this price and the electricity spot price.

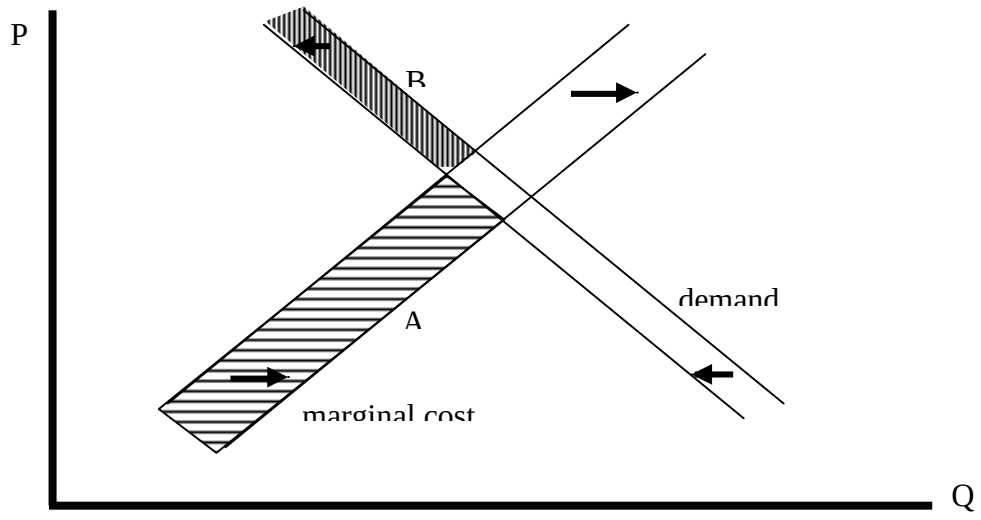
Finally, with imperfect financial markets, large industrial end users and LDCs can hardly hedge this risk. Although a long term contract with the pipeline would lock in quantity and price, they still face the risk of whether they will actually use that quantity (and pay for it regardless if it is used). In contrast to electric generators, there are no mechanisms that would allow them to hedge this risk. As a result, large industrial end

users and LDCs should require a risk premium when evaluating a given contract. The magnitude of the risk premium necessary for a large industrial end users risk premium will differ from that of LDCs. The key determinant of the risk premium for a large industrial end user is the contribution changes in capacity rights prices make to the variance of the end user's revenues. This will in turn depend on the importance of capacity rights prices per unit of value added. For energy intensive industries (e.g. cement, metallurgy), we expect operating profits to respond strongly and negatively to changes in capacity rights prices. As a result, we expect a significant negative risk premium for these end users. LDCs, on the other hand, can pass this risk to their captive customers, as they are regulated monopolies. That is, ultimately these captive customers (residential, commercial and small industrial) bear this risk. Again the key determinant of the risk premium is the contribution that changes in capacity rights prices make in these captive customers' income. We expect variations in energy capacity rights prices to contribute very little to the volatility of these customers' income, as such, their risk premium required is likely to be very small

In sum, an efficient contract would transfer some of the market risk away from the pipeline company towards electric generators, who can completely hedge it; LDCs, who are close to being indifferent about this risk; and large industrial end users, who can be very sensitive to this risk. Long term contracts can achieve this risk transfer. It is important to note that the case analyzed here assumes that ownership of these companies is not dispersed. If these companies were traded on a world equity market and ownership dispersed, then financial markets would be more complete as shareholders could diversify away from market risk by trading shares of the companies. The market risk would be incorporated in the share price. This is an extreme case that is hardly a reality. Ownership of these companies is not dispersed. Market risks cannot be completely transferred through financial markets, and thus the different companies have comparative advantages in bearing market risk. These differences in the ability to bear risk are reflected in risk premia differences, which suggest different valuations for a given long

term contract[42]. Transferring risk to those parties that have a comparative advantage in bearing that risk increases the surplus of both parties. This is depicted in figure 3.2.

Figure 3.2: Risk Allocation and Welfare Increase



Transferring some of the market risk away from the pipeline allows the pipeline to decrease the marginal cost of investment, which is represented by a downward shift in the marginal cost curve. End users, on the other hand, bear more of this risk and are thus demand less for a given price. This is represented by a downward shift in the demand curve. Overall, there is an increase of overall efficiency (measured as the area between the two curves) as area A is bigger than area B. Again, this is the result of comparative advantages in the ability to bear this risk.

3.3.1.2. Investment Cost Risk

Clearly the pipeline company has a comparative advantage in bearing this risk. This advantage derives from better information, and in particular, stronger influence over the outcomes relatives to the other players. As a result, the pipeline company should

[42] Risk premium affects the discount rate used for the evaluation of these contracts. Thus a party with a higher risk premium, and thus a higher discount rate, will have a lower valuation for a given contract than a party with a lower risk premium.

want a disproportionate exposure to this risk. A contract to transfers most of the risk to the pipeline might include some penalties for delays in the completion of the project. Moreover, such contract does not guarantee efficiency in the development of the project. A cap on allowed investments would give the pipeline the incentives to reduce investment costs as it would be the residual claimant to all investment savings. With such contract, the interests of the pipeline and the end users would be aligned.

3.3.1.3. Country-Macro-Political Risk

This risk is important when considering investment projects offshore by a pipeline company[43]. Country-macro-political risks refer to the viability of economic programs in the host country. The pipeline company can somewhat diversify this risk as it can participate in investment projects in various regions of the world. In contrast, end users, with local or government shareholders, are overexposed to this risk[44]. Following Lessard (1996), there are various ways parties can mitigate this risk while at the same time achieving efficient allocation in the other dimensions. The purchase of country risk insurance (from institutions like Overseas Private Investment Corporation for example) or the hedge based on puts on traded shares of local firms are just two options that may be considered.

Part of the economic viability of the host countries, and hence the viability of pipeline projects, includes whether and how "the rules of the game" are likely to change. That is, whether the decision rights will change or whether existing contracts will be enforced. In the case of emerging countries, this risk can be very important and can, at the end, be the determinant factor of whether a project is implemented or not. As noted by Lessard (1996), the stability of the rules of the game depend on how the discretionary power of regulators and policymakers is used. As such, comparative advantage on bearing this risk will arise when one or more parties have influence over the process and

[43] See Lessard (1996). for a more complete discussion of the principles of risk and valuation in the context of foreign direct investment.

[44] Of course, electric generators can be multinationals as well as large industrial end users. As such, these companies can also diversify this risk and can bear it.

outcome. Local strategic investors can have an advantage in taking this institutional risk because of their leverage over the political process. For example, pension funds could be an important strategic investor. Because pension funds represent the savings of "widows and orphans", they can have an important influence over the political and regulatory process relevant to pipeline operations[45]. However, these passive investors may not want to be exposed to other risks (e.g. investment cost risks) and thus may want to participate in the project through preferred shares or options on the equity of the project once project is fully operational. Investments by international organization (e.g. World Bank, IADB) can also help these risks to the extent that they can exert pressure and influence on policy makers and regulators to avoid changes in the "rules of the game".

3.3.2. Contracting Risks and Contracting Efficiency

Contracts are incomplete by nature. It is impossible to determine in advance the responsibilities of each contracting party for each possible state of nature. Moreover, uncertainty may lead to huge disparities between contract terms and market conditions. As a result, there will be instances where one or more contracting incentives will have the incentive to act unilaterally and renege and renegotiate the agreement. This can lead to costly gaming by the different players which must be incorporated by all players when structuring the original contract. In the end, these contracting risk may reduce the overall attractiveness of the project. An efficient contract would thus minimize these contracting strains.

The existence of a secondary market for capacity rights can prove valuable at reducing contracting strains. Indeed, when end users find the contract does not reflect their interests anymore, (for example, a secondary market price well below their contractual price) they may transfer their contractual obligations to other end users

[45] See for example the case of privatization in Bolivia. Government shares of state owned companies were transferred to all Bolivians through pension funds. This has limited the ability of policymakers to change the "rules of the game" affecting the privatized companies.

through capacity release. In theory, the price of the secondary market is both transparent and unbiased, and thus should not be subject to extensive negotiations at the time of the transfer. More importantly, the pipeline is indifferent with respect to this transfer. Similarly, the pipeline, when feeling the original contract does not reflect its interests anymore (for example, when secondary market prices are far above the contracted price), may issue new rights in the primary market. This would tend to reduce the secondary market price, and thus the originally contracted price would tend to reflect more the interests of the pipeline. However, it is important to note, that an inefficient secondary market (in terms of information sharing or liquidity) will have a limited value in reducing contracting rights. In such instances, then, short term contracts can present advantages over long term contracts since renegotiations of the contracts will necessarily reflect any changes in market conditions[46].

3.3.3. Information and Contracting Efficiency

Asymmetries in information can lead to inefficient investment levels. A pipeline company needs to know demand for gas in order to make the efficient investment in capacity. However, end users might know more about demand than the pipeline company. An efficient contract must thus provide a mechanism that gives the incentive to end users to truthfully reveal their information about demand to the pipeline company. Long term contracts can serve this purpose. By transferring market-price risk to end users, as argued before, they make end users the residual claimant to the value of the pipeline investment. As such, end users have the incentive to estimate their demand as carefully and honestly as possible[47]. Short term contracts do not provide for these incentives as end users do not bear the cost of investment. In a world of uncertainty, end

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[46] The theory behind incomplete contracts is developed in Grossman and Hart (1986), Hart and Moore (1988) and Hermalin and Katz (1991) among others.

[47] See Michael Habib (1996) for a discussion of information asymmetries and the role of contracts in the development of electricity generation projects. Grossman (1977) and (1992) provide a theoretical explanation for the informational role of futures markets. Allaz and Vila (1993) extend the role of futures markets to induce competition in a duopoly market.

users have the incentive to claim higher demands to the pipeline company (which we assume will translate it into investment), thus minimizing the possible outcomes over which they are unable to satisfy demand as a result of lack of capacity. Inducing end users to reveal their information truthfully requires that they bear the costs of the required capacity. That is precisely what long term contracts achieve.

3.4. Infrastructure and Contracts

The previous section identified the different risks and issues that need to be considered when evaluating the investment in a pipeline project. We briefly discussed how long term and short term contracts can handle these issues. In this section, we analyze, from a social welfare point of view, the desirability of short and long term contracts with respect to the issues identified above and discuss how this desirability varies as a function of the infrastructure. We will concentrate on three types of contracts discussed in chapter one.

1. Long term contracts, where the pipeline sells capacity forward in the primary market and is not allowed to issue new rights in the primary short term markets. However, the pipeline is allowed to discriminate rights between heating and non heating seasons.
2. Short term contracts, where the pipeline sells capacity rights in the primary short term markets only, and is not allowed to participate in the primary long term contracts. That is, at the beginning of each heating and non-heating season, the pipeline issues capacity rights valid for one season only.
3. Long term contracts with no seasonal component, where the pipeline sells capacity in the forward market only (as in the first contract structure), but is not allowed to discriminate between heating and non-heating seasons. Rights are equally valid in both seasons. This contract structure is referred as the equivalent contract structure in the first chapter.

We will judge desirability of these contracts as a function of how they rate with respect to five issues: (i) their efficiency in allocation market-price risk; (ii) their ability in reducing contracting risks; (iii) their ability to handle asymmetries in information; (iv) their ability to limit monopoly rents by pipeline; and (v) the incentives they provide for pipeline investments. The last two issues directly relate to the first two chapters of the dissertation, and should be seen in conjunction with regulation. As we saw in the first two chapters of the dissertation, storage does not completely eliminate the ability of the monopolist pipeline to exert market power. There is still a role for regulation in controlling and limiting the abuse of power by the pipeline. However, the regular caveats in regulation (information asymmetries, moral hazard) can limit the extent to which regulation can successfully limit the pipeline's ability to extract monopoly rents. Storage can facilitate the regulatory task by introducing the pipeline in the valley as a competitor to the pipeline in the peak. As argued in the first two chapters, the strength of this competitive effect will depend on the nature and structure of the contracts between the pipeline and end users. It is in this sense that we should see storage as a *complement* to regulation. We do not judge the desirability of contracts with respect to allocation of investment cost risks and country-macro-political risks because the mechanisms to hedge and manage these risks can be equally applied to all three contract structures with no change in their relative value.

Our discussion will focus on three infrastructures scenarios: (i) a monopolist pipeline, (ii) a monopolist pipeline in the context of storage, and (iii) a pipeline that is part of a well integrated pipeline grid system. In the first two scenarios, before the pipeline investment, there is no pipeline infrastructure in place delivering gas. As such there is *no* capacity rights market and thus no capacity price that could guide the pipeline investment. Once completed, the pipeline will have a monopoly over the transportation of gas into this market. In the second scenario, the pipeline investment is accompanied by investments in storage[48]. In both scenarios, contracts and regulation will play a key role in providing the incentives for pipeline investment. In contrast, the third scenario

[48] Our analysis does not discuss the incentives for storage investments. We assume that they "are just there" and developed in conjunction with the pipeline.

entails a developed pipeline grid with many pipelines delivering gas into this market from many producing areas, as well as a competitive storage sector. In this third scenario, competition is so intense that no single pipeline is assumed to have market power in transporting gas. Hence, regulation is not a critical component in this scenario. Moreover, such integrated markets are more likely to develop futures markets because of the liquidity that they have. We assume the existence of a futures price, which provides the incentives for pipeline investment. Of course these scenarios represent two extremes. The first two scenarios represent infant markets whereas the third scenario represents well developed and mature markets such as the US market. Of course, there is a continuum of possibilities between these two extremes. Understanding the relevant issues at these two extreme cases allows us to capture the intermediate cases as well.

Table 3.1 below summarizes the interaction between the different contracting regimes and physical infrastructure.

Table 3.1: The Interaction of Contracting Regimes and Physical Infrastructure

	Market Risk Allocation			**Reduction in Contracting Risk**			**Information Sharing**			**Limit Monopoly Rents**			**Incentives for Pipeline Investments**		
Infrastructure\ Contract Type	**LT**	**ST**	**EQ**	**LT**	**ST**	**EQ**	**LT**	**ST**	**EQ**	**LT**	**ST**	**EQ**	**LT**	**ST**	**EQ**
Monopolist Pipeline	+	-	+	-	+	-	+	-	+	+	-[1] +[2]	++[3] -[4]	+	++[1] +[2]	+[3] -[4]
Monopolist Pipeline and Storage	+	-	+	-	+	-	+	-	+	+	-[1] ++[2]	++[3] -[4]	+	++[1] +[2]	+[3] -[4]
Integrated Pipeline System	+	-	+	0	0	0	0	0	0	0	0	0	0	0	0

Note: Contract Type corresponds to the contracting regimes described above.
0 represents indifference and/or no effect.
+ and ++ represent a comparative advantage over the other contract types.
- and -- represent a comparative disadvantage over the other contract types.

1. When uncertainty is high (see chapter two)
2. When uncertainty is low (see chapter one)
3. When seasonality is high (see chapter one)
4. When seasonality is low (see chapter one)

The table shows that there is no single contracting regime that dominates the others in all five dimensions and across all infrastructure scenarios. It is important that regulators understand interaction between contracting regimes and physical infrastructure, as it is critical for the efficient operation of the natural gas industry. Note that the regulator's choice of contracting regime will depend on the relative weight of the five dimensions outlined. Thus, for example, regulators in infant markets such as the Southern Cone where the emphasis is on pipeline investment might choose a contracting regime based on its relative advantages to provide incentives for pipeline investments. Moreover, regulators must also understand how the five dimensions interact with each other. Thus, for example, a more efficient risk allocation of risk might increase the incentives for pipeline investment. This discussion suggests that selecting a particular contracting regime is indeed very complex at best. Regulators must weigh the different considerations at hand.

From the table, we see that long term and the equivalent contract structures are the more efficient with respect to allocating risk and providing incentives for information sharing across all infrastructure scenarios. In contrast, short term contracts reduce contracting risks more efficiently than the other two. It is only when considering the effects of the contracting regimes on the ability to limit monopoly rents and to provide incentives for investments that the relative value of the contracting regimes depend on the level of uncertainty and seasonality. Based on the results of chapter two, at high uncertainty levels, a long term contract regime is more suited, from a social point of view, than a short term contract regime to limit the monopoly power of pipelines. In contrast, at low uncertainty levels, the two regimes are equally effective in limiting monopoly rents. The reason for this is that short term contracts allows the monopolist pipeline the flexibility to adjust once uncertainty unfolds. This flexibility has a greater value with high levels of uncertainty. When storage is present, a long term contract regime dominates again a short term contract regime at high levels of uncertainty. However, at low levels of uncertainty, the short term structure dominates the long term contract structure. As argued in chapter one, a short term contract regime introduces a stronger competitive effect of storage. With respect to providing incentives for

investments, the short term contract regime dominates at high levels of uncertainty, but they are equally effective at low uncertainty levels.

By the same token, based on the results of chapter one, the equivalent contracting regime is more effective at high levels of seasonality than the other two at limiting monopoly rents. In contrast, at low levels of seasonality, the equivalent contract structure is dominated by the other two structures. Similarly, at high levels of seasonality, the equivalent structure yields the same investment levels as the long term contract structure, but yield lower investment levels than either of the two other structures at low level of seasonality.

The table also shows that in the context of integrated pipeline systems, the different contracting regimes make no difference with regard to reduction in contracting risk, information sharing, limits to monopoly power and investment incentives. There is no advantage in using contracting regimes to reduce contracting risk because the market is a more effective mechanism. With an integrated system, we expect a highly liquid capacity rights market because of the large numbers of participants in it. Thus, it is easier to transfer the contractual obligations to other end users when these obligations go against the interests of the original parties. Similarly, the futures market characteristic of integrated markets provide a mechanism for information sharing as it gives an unbiased estimate of the future value of pipeline capacity. Futures prices contain the information about gas demand that might be otherwise difficult for the pipeline to obtain[49]. Finally, by definition, there is no market power in an integrated pipeline system. The competitive outcome will prevail regardless of the contracting regime. Similarly, competitive investment incentives will prevail. The contract structure would have no effect. This shows how contracts can serve as substitutes to markets when these fail. The first two scenarios presented market failures associated with the monopolist position of the pipeline. However, different contracting regimes were able to alleviate these problems.

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[49] See Habib (1996) for a discussion of the informational role of futures markets in the context of investments in electric generation.

It is important to note the role that marketers play in integrated pipeline markets. Marketers secure the competitive outcome characteristic of integrated markets. They pool sellers and buyers enhancing competition. Moreover, in order to offer the least expensive alternative to end users, marketers will take advantage of any arbitrage possibilities that may arise within an integrating system, moving gas through pipelines with lower-than-equilibrium capacity price. As such, we expect marketers to play a pivotal role in achieving the "law of one price" in the entire system where prices across points differ only by the capacity price which reflects the relative scarcity of capacity to those points. Participating across the entire pipeline systems gives marketers the ability to diversify local market-price risk better than local end users. Marketers by participating in various regional markets of an integrated system effectively pool the regional risks and can thus bear more of regional risk, unlike end users in a particular region within the system. It should not be surprising then that in an integrated system, pipelines contract with marketers rather than end users as they have a comparative advantage in bearing market risk. Marketers have also the advantage of participating across energy markets (electricity, gas, etc) by selling units of energy rather than volume of gas for example. This flexibility allows marketers to arbitrage across energy markets making them more efficient and introducing financial instruments that would not be otherwise available.

3.5. Conclusions

In this last chapter of the dissertation, we have tried to integrate our analysis of the first two chapters into a more general discussion of incentives and contracts in pipeline investments. Our aim has been to determine the desirability of long and short term contracts in terms of risk allocation, information sharing, contracting risk and the ability to strengthen the competitive effect of storage on monopolist pipelines. We have seen in the second section of this last chapter that the incentives for pipeline investments depend on the capacity price on the primary markets. The price in this primary market will depend on whether the pipeline can credibly commit not to issue new rights in the

future or not. Secondary markets for capacity rights guarantee that capacity will be used by those end users that value it the most.

We have also seen that long term contracts play an important role in providing mechanisms for efficient risk allocation and information sharing. Without such mechanisms, projects that are economically attractive in aggregate terms may be unattractive to a particular party and thus may not be developed. Moreover, contracting must also be seen as complementary to regulation in that it can strengthen the competitive effect of storage and limit the ability of a pipeline to extract monopoly rents. We saw that in the context of an integrated pipeline grid, long term contracts have less of an important role as there are market mechanisms that can effectively substitute long term contracts in terms of information sharing and reduction of contracting risks. Long term contracts are still needed in order to efficiently allocate risk. However, we expect the more integrated the pipeline system becomes, the shorter the average length of long term contracts between pipeline and end users will be. Indeed that has been the case in the US[50]. In this sense, pipelines will be bearing more of market risk than with less integrated systems. However, as noted earlier, the emergence of marketers who have a comparative advantage in bearing this risk might alleviate this situation.

[50] See Energy Information Administration (1995) and (1996).

Conclusions

The starting point in this dissertation was a restructured natural gas industry with a market for pipeline capacity rights. In addition to purchasing gas at the wellhead, end users must purchase capacity rights in order to transport gas to the burner tip. In such context, access to pipeline should be viewed as a separate asset complementary to gas. The dissertation argued that the value of capacity rights prices is twofold. First, they lead to an efficient allocation of scarce pipeline capacity, as those end users that value it the most will obtain it and the marginal cost of the service is equal to the benefit to the marginal end user. Second, they represent the benefit that end users put on pipeline capacity, and therefore can guide capacity additions in an efficient manner. Of course, the value of this price signal depends the transparency of the capacity price. The dissertation focused on two sources for the non-transparency of price signals: (i) the monopoly position of pipelines, and (ii) the non-existence of price signals in those markets where gas is not already flowing. Moreover, in the context of the second source, even if there is some sort of price to guide investments, there might be some other market imperfections that could lead to inefficient investment levels.

The dissertation analyzed the interaction between contracts and infrastructure, in particular storage, as a solution to these imperfections. In the Coasian tradition, this dissertation viewed contracts and infrastructure as substitutes for market mechanisms in the presence of market failures. The first chapter analyzed this interaction in the context of certainty. It argued that storage introduces a physical link between market in the

future and market in the valley. It is precisely the introduction of this link that renders the pipeline in the valley as a competitor to the pipeline in the peak. Moreover, the strength of this competitive effect of storage greatly depends on the contract structure between pipelines and end users.

The second chapter extended the analysis by incorporating uncertainty. The main effect of uncertainty is that it reduces the competitive effect of storage. Storage decision is irreversible in the sense that once uncertainty unfolds, end users cannot adjust their storage decision. As such, storage decision, although efficient *ex-ante*, is always inefficient *ex-post*. This ex-post inefficiency reduces the competitive effect of storage. The conclusions of the first chapter are still robust in the context of uncertainty. However, the relative value of the contract structures analyzed varies with the magnitude of the uncertainty. Finally, the third chapter was concerned with a qualitative approach to the investment decision. It recognized different market imperfections, including differences in the ability of pipelines and end users to bear risks, and informational asymmetries. These market imperfections could potentially lead to the failure to develop pipeline projects that are economically attractive from a social point of view, but unattractive to one of the parties. The chapter analyzed how different contracting mechanisms could alleviate these problems and hence lead to efficient investment.

The dissertation suggests a different approach to thinking about capacity rights markets and monopoly power in them. This new approach hints at going beyond the functional aspects of capacity rights markets as access to transportation services. Traditionally, regulators have emphasized the Herfindahl-Hirschman concentration index (HHI) as a measure of market power[51], and hence the extent to which allocative efficiency is achieved. The HHI is too narrow a measurement and neglects many important aspects of the economics of capacity rights markets[52]. In particular, the HHI neglects three dimensions that need to be considered for a comprehensive analysis of

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[51] See Dan Alger (1996) for a more complete discussion of FERC's policies to allow market based rates for pipeline transportation.

[52] The HHI takes the square of the percentage market share of each pipeline. FERC does not allow market based rates if one of the pipelines have an HHI of 1800 or above (equivalent to 42% of market share).

market power and allocative efficiency. These dimensions are (i) intertemporal integration of capacity rights markets, (ii) interregional integration of capacity rights markets, and (iii) integration with other energy markets.

First, the intertemporal integration of markets is concerned with the competitive effect of storage, which is the focus of this dissertation. As argued, storage introduces a competitive effect that limits the ability of the pipeline to extract monopoly rents. By construction, HHI does not include this competitive effect of storage. The model presented in this dissertation shows that pipelines might have 100% market share (equivalent to a level of 10,000 HHI) and yet cannot fully exploit their monopoly position because of the competitive effect of storage and contracts. Thus, the HHI *overestimates* the market power of the pipeline. As a first measure, market definition should be expanded to include storage deliveries into the HHI. Of course, this dimension is relevant only for those markets that present physical and geological characteristics suitable for the use of depleted fields and salt caverns as storage facilities.

Second, interregional integration of capacity rights markets is concerned not only with infrastructure already in place but also with potential pipeline projects. In particular, interregional integration is concerned with the contestability of pipeline markets. The HHI is a measure based on *actual* market shares, and by construction neglects the market shares of *potential* entrants. Again, the HHI could lead to overestimation of market power. With low barriers to entry, monopoly pipelines would tend not to drive prices up in capacity rights markets, if they know that could drive potential competitors into the market. A single pipeline could have 100% market share, but its ability to extract monopoly rents could be severely limited by the threat of entry. The strength of this threat will depend on how large barriers of entry are. High investment costs and long lead times in the completion of pipeline projects could introduce large barriers to entry. This is indeed the case for some isolated regions that require large investment sums for a pipelines. Other regions, however, benefit from low barriers of entry, as potential entrants could build inexpensive connections with adjacent and nearby pipeline systems.

Third, integration across energy markets is concerned with alternative sources of energy for end users. The ability of end users to switch to alternative sources provides a natural bound on the ability of a pipeline to extract monopoly rents. Again, the HHI ignores the competition from other sources. This is particularly important for electric generators who, through their increasing use of combined cycle technology, have the ability to switch to fuel oil. This switching option is inherent in the technology and therefore is free, making the competitive effect of fuel oil very strong. Of course, the more important electric generation is in end user demand, the stronger the competitive effect of fuel oil is, and hence the more pipeline is constrained in extracting monopoly rents. In the extreme case where all end user demand comes from electricity generation, the price of gas (which includes capacity rights) will be determined by world price of fuel oil. In this sense, the gas market will not be regional, but rather completely integrated to the world market for fuel oil. Moreover, the competition from alternative sources of energy is not restricted to the burner tip end of the pipeline. Electric generation can bypass the capacity rights market altogether and generate electricity near the producing areas and transmit it, through the high voltage system, to the burner tip region. That is, the alternatives faced by electric generators limits the ability of a pipeline to extract monopoly rents in the capacity rights market. Again, the HHI does not incorporate this issue and thus overestimates the market power of pipelines.

The three dimensions discussed above introduce *substitutes* to capacity rights markets. End users are not completely hostage to the use of capacity from a monopolist pipeline. It is important that regulators understand these dimensions when analyzing market power of pipelines. These substitutes limit the extent to which pipeline can extract monopoly rents contributing to the attainment of allocative efficiency. It is important to note that the arguments presented here do not aim at *eliminating* regulation altogether. Indeed, the monopoly power of pipelines could be so strong that regulation is needed to guarantee they do not extract monopoly rents. However, regulation can never perfectly eliminate market power. Informational asymmetries necessarily restrict the efficiency of regulators. Moreover, cost of service regulation can introduce perverse

incentives such as the Averch-Johnson effect, which induces the excessive accumulation of capital[53]. Instead, the dimensions discussed above should be seen as *complementary* to regulation. They represent *market-based* mechanisms, and as such can strongly and efficiently limit the monopoly power of pipelines. Regulators should treat these dimensions as another tool in their arsenal against pipeline monopoly power. Regulator should thus provide stronger incentives so that these three dimensions become more important and therefore contribute to allocative efficiency.

Incentives for storage investments become a critical policy variable for regulators concerned with the intertemporal integration of markets. These incentives include, for example, reducing the transaction costs associated with the approval of storage investments. In addition, regulators should abstain from regulating storage prices as it introduces inefficiencies and hinders the competitive effect of storage. There are no economic reasons justifying the regulation storage. The difference in peak and valley prices provides a natural bound to storage prices. Moreover, there are no economies of scale in storage investments as the most economical storage facilities are depleted fields and salt caverns. Investments in these facilities vary with the physical and geological properties of a particular region, and have a linear relationship with volume. As argued in the first chapter, investments in liquefied natural gas (LNG) container facilities may exhibit economies of scale as the surface area has a linear relationship with radius of the container, and volume has a squared relationship. However, the operational costs of these facilities are prohibitively expensive as it involves the liquefaction and regasification of natural gas.

Concerning the interregional integration of markets, decreasing barriers to entry for pipeline investment could be an option for regulators. Eliminating any approval process (except for engineering and safety standard purposes) would greatly reduce the barriers to entry for potential competitors thereby limiting the monopoly power of pipelines. Finally, with regard to the integration of energy markets, providing the incentives for end users to easily switch sources of energy could prove valuable to

[53] See Laffont and Tirole (1993) for a comprehensive analysis of the limitations of regulation

regulators. For example, regulators could provide the incentives for marketers that arbitrage across energy markets selling Btus rather than volume of gas. The emergence of such marketers could lead to the convergence into a single energy market. This is indeed the trend in the United States resulting from the restructuring of the electricity and natural gas markets. Companies such as Enron are leading the way in the innovation of financial and physical instruments that arbitrage across energy markets. This type of arbitrage introduces more flexibility to end users, thereby completing the market and introducing more competition to the pipeline.

This dissertation also suggests the important role of financial markets for pipeline investments. Complete financial markets allow for the efficient allocation of risk to those parties that have a comparative advantage in bearing a particular risk. As such, conditional on allocative efficiency in capacity rights markets, only those socially attractive investments will be made. However, incomplete financial markets could lead to suboptimal investment levels even if there is allocative efficiency in capacity rights prices markets. This is so because some parties might be overexposed to a certain risk and there are no mechanisms that can alleviate this situation. Thus, for example as argued in chapter three, if ownership of pipeline, LDCs, and electric generation companies is wide and dispersed through equity markets, then risks associated with a pipeline project will be imbedded in the price of equity of these companies. As such, equity markets will represent the sufficient mechanism to allow efficient risk allocation. In contrast, if ownership is not dispersed, there is a need for mechanisms that would complete the financial markets and allow for a more efficient allocation of risk and thus more efficient investment levels.

Between financial markets and the three dimensions discussed earlier, lie contracting regimes. That is, contracts play a *dual* role of achieving allocative efficiency and providing incentives for efficient investments. As argued in the first chapter of the dissertation, the contracting regime plays an important role in the competitive effect of storage. As such, contracts play an important role in the intertemporal integration of markets. Similarly, contracts can determine the extent to which there are barriers to entry in the pipeline sector. For instance, end users might have take-or-pay clauses in their

capacity contracts with existing pipelines. Such contracts could considerably increase the costs of switching to another pipeline, representing high barriers to entry into the sector. Such contracts would thus increase the ability of a monopolist pipeline to extract monopoly rents. On the other hand, as argued in the third chapter, contracts can be seen as completing financial markets in that they allow a more efficient allocation of risk. However, the role of contracts can be conflicting as a function of seasonality, uncertainty and length of peak period. For example, following the analysis in chapter one, markets with low seasonalities should benefit with short term contracts as they strengthen the competitive effect of storage. But short term contracts do not lead to an efficient allocation of risks, following the analysis in the third chapter, and thus can lead to inefficient levels of investments.

It is important that regulators understand this dual role of contracting regimes. In mature markets such as the United States, characterized by the vast pipeline infrastructure already in place, the emphasis is on limiting the monopoly power of pipelines, rather than on the development of new pipeline projects. In addition to providing the incentives for intertemporal, interregional and energy markets integration as discussed earlier, regulators could also use contracting regimes to strengthen the effect of these types of integration on the ability of pipelines to extract monopoly rents. That is, regulators could restrict those contracting regimes that do not strengthen the competitive effect of storage or that introduce high barriers to entry into the pipeline sector. For example, regulators could restrict contracts with seasonal components in those markets with high seasonalities and allow only short term contracts in those markets with high seasonalities and low uncertainty levels.

In contrast, the emphasis in infant markets is not only on limiting the monopoly power of pipelines, but also on providing incentives for efficient pipeline investment. The key for the successful development of these markets lies on the ability of regulators to strike a balance on providing incentives for efficient investments and limiting the monopoly power of pipelines. It is important that regulators recognize there is a tradeoff in the use of contracting regimes. For example, although long term contracts are necessary for the efficient allocation of risks and hence for efficient investments, they can

also introduce higher barriers to entry and weaken the competitive effect of storage. That is, long term contracts while beneficial to efficient investments may introduce deviations from allocative efficiency. However, this trade off is less dramatic the more financial markets are complete. As noted earlier, the more complete financial markets are, the less important long term contracts are as mechanisms for the efficient allocation of risk and the more freedom regulators have in using contracting regimes as tools for allocative efficiency.

It is important to note that regulators in infant markets have an additional tool for limiting the monopoly power of pipeline not available to regulators in mature markets where infrastructure has already been developed. By auctioning the rights to construct and operate a pipeline, regulators can introduce *ex-ante* competition that would guarantee that the pipeline does not extract monopoly rents even if *ex-post* the pipeline is a monopolist. Regulators can define the auction rules so that the winner is selected based on the capacity price it will charge. A sufficiently large number of participants will guarantee that the winning price will equal the competitive price[54]. Moreover, the contracting regime does not matter since in a competitive equilibrium contracting regimes are redundant in that they all achieve the competitive outcome. This auction process introduces a "virtual competition" that effectively completes the market and hence achieves allocative efficiency. Of course, this tool assumes a sufficiently large number of participants. This assumption is not necessarily true for small isolated regions that do not attract large amounts of investments. In these cases, regulators will have to allow some monopoly rents in order to induce participants to invest in a pipeline project. However, they can limit this monopoly power to the minimum required for the participation in the project by providing the incentives for intertemporal, interregional and energy markets integration as discussed earlier; and by using contracting regimes to strengthen the effect of these types of integration.

[54] See Salanie (1997) for a discussion of the theoretical work on auction theory.

Future Research

This dissertation introduces a number of interesting arguments that can be expanded in future research. This future research can be divided into two directions. The first line of research directly tests the propositions introduced in the dissertation. In particular, future researchers may test the relationship between contracting regimes between pipelines and end users, seasonality, uncertainty and duration of peak period. The emphasis of this research may be on how pipeline profits changes as a function of contracting regime while controlling the other variables (uncertainty, seasonality and duration of peak period). Following the first two chapters of the dissertation, research could, for example, hypothesize that a long term contract with seasonal components should lead to higher profits when seasonalities are high and uncertainty low. In contrast, a long term contract with no seasonal component structure should lead to higher profits when seasonalities are low. This already poses an interesting puzzle as the current trend in the natural gas industry in the United States is long term contracts with no seasonal component. Future research could explain whether this trend is consistent with the model presented here in that seasonality is relatively low in these markets, thereby making this trend profit maximizing from the point of view of the pipelines, or whether there are other considerations that can explain this trend.

Within this first line of research, the effect of contracting regimes on pipeline investment could also be tested. In particular, future researchers may test whether for low uncertainty levels, the short term and long term contracts lead to identical investment levels. Moreover, future researchers may also study the extent to which long term contracts serve as a mechanism to allocate risk among the different parties. That is, researchers may study the pattern of long term contracts as a function of dispersion of the ownership of the different companies, the extent to which there is an electricity futures market, and the physical integration among the different regions. Following the analysis of the third chapter, researchers could hypothesize for example that the more disperse ownership is, the less important the role of long term contracts in allocating risks. Moreover, they could also hypothesize that the more integrated a market is and the

stronger the presence of marketers is, the more important the activities of marketers in the primary markets for capacity rights.

The second line of research is related to the broader argument of the dissertation that regulators need to look at market power in capacity rights markets beyond the functional aspects of capacity rights markets as access to transportation services. In particular, future research could concentrate on how important storage markets are in undermining the monopoly power of pipelines by looking at the deviation from monopoly rents resulting from storage. Also, researchers could also study the extent to which low barriers to entry into the pipeline sector can undermine the ability of pipelines to extract monopoly rents. Finally, the importance of integration across energy markets could also be studied. Such studies would give regulators the empirical evidence needed to understand the extent to which pipelines can price monopolistically.

It is important to note that the empirical studies outlined above could indeed prove difficult because of data availability and experiment set up. The analysis in this dissertation assumes *no regulation*, and concentrates on the monopolist being completely free in its maximization problem. This is not necessarily true in real life. The testing of the propositions presented in this dissertation would require looking at pipeline profitability before and after the introduction of storage for example. Because of regulation of prices, the change in profitability might not fully reflect the impact of storage. By the same token, the impact of different contracting regimes might be underestimated as regulation in prices might impose some restrictions on pipeline ability to react to the different contracting regimes.

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