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NOTAT

Natural Gas Network and Access Pricing

Kristin Linnerud

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NOTAT

Postboks 133, 6851 SOGNDAL telefon 57676000 telefaks 57676100

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SAMANDRAG

Formålet med notatet er å utvikle en normative model for prising av gasstransport. Modellen tar utgangspunkt i nyere reguleringsteorier, der kontrakten mellom en regulator og en bedrift er preget av informasjonsasymmetri og kan beskrives v.h.a. prinsipal-agent modeller. Innledningsvis beskriver jeg gassmarkedet og behovet for regulering. Deretter utleder jeg en normativ prismodell. Til slutt evaluerer jeg ECP-regelen mot min normative modell.

SUMMARY

This paper discusses access pricing for a natural gas pipeline. In doing so, I use the new economics of regulation which is an application of the principal-agent methodology to the contractual relationship between regulators and regulated firms. After presenting the regulatory context, I develop a normative model for regulating the access prices to a natural gas pipeline in the presence of competition in the retail market for natural gas. Finally I compare the Efficient Component Pricing rule with my normative pricing model .

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Preface

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Sogndal, 15. February 2005

Content

Norway has rich supplies of crude oil, gas and waterfalls. Hydropower is the main energy source for stationary energy consumption, while natural gas accounts for only 1% of our stationary energy consumption. Recently, there has been a political pressure towards increased domestic use of natural gas. This implies developing an infrastructure for natural gas in some areas of Norway that will supplement the well developed infrastructure for electricity. The resulting market for transmission or distribution of natural gas will most likely be one of imperfect competition. Imperfect competition can lead to an efficiency loss and there might be a role for government intervention in terms of regulation or competition policy.

This paper discusses access pricing for a natural gas pipeline. In doing so, I use the new economics of regulation[1] which is an application of the principal-agent methodology to the contractual relationship between regulators and regulated firms. In section 1 I present the regulatory context. In section 2 I develop a normative model for regulating the access prices to a natural gas pipeline in the presence of competition in the retail market for natural gas. In section 3 the relationship between the optimal model and a simple and influential pricing rule; The Efficient Component Pricing Rule, is investigated. I conclude the paper in section 4 by discussing the limits of the current approach and presenting directions for my further research.

1 The regulatory context

1.1 Theory and concepts

Regulation can be defined as the government intervention in some specific markets in response to normative objectives and triggered by the existence of market failure. Investing in natural gas pipelines, market failure can occur due to;

1. a cost structure characterized as a natural monopoly,
2. large sunk costs that give rise to the hold-up problem and

[1] The term "new economics of regulation" was first used by Jean-Jacques Laffont in his Presidential Address to the Econometric Society in 1994 (Laffont J-J (1994).

3. informational asymmetry between agents in the market.

A production activity is a natural monopoly for a certain production quantity if this quantity can be produced cheaper by one single producer than by any other organization of the production. The standard solution to this problem is to give the right to supply to one firm. This firm must produce the socially optimal quantity of the good, and is compensated for the loss of doing so.

Large, irreversible investments can give rise to opportunistic behaviour. Faced with one customer, the investor might be forced to sell its services at a price which only reflects the avoidable costs. Furthermore, a regulator unable to commit his actions fully in advance, may find it optimal to alter price control ex post after the regulated firm has sunk its investment. Knowing this, socially beneficially investments might not be undertaken in the first place, and there would be a hold-up problem. In the case of symmetric information, this could be solved by designing complete contracts that specified the terms of trade in every state of nature that could occur. However, even in the case of symmetric information, incomplete regulatory contracts and the inability of the regulator to commit itself into the future represents a constraint on the relationship between the regulator and the firm.

Finally, information asymmetry where the firm has private information about its technology, demand and/or effort might give rise to strategic behaviour in the firm and complicate the design of an optimal regulation. The informational asymmetry represents informational constraints on the design of an optimal regulatory policy. Private knowledge of exogenous variables like productivity or demand leads to problems of adverse selection, while private knowledge of endogenous variables such as cost reducing effort leads to problem of moral hazard.

There exist at least four approaches to the regulatory problem above:

1. regulate the market participant's choice variables, like price and quality[2],

[2] Examples are rate of return regulation, revenue cap regulation or price cap regulation.

2. define contracts which specify the rights and duties of the participants in the natural gas network,
3. regulate by harnessing the competitive forces and
4. control ex post.

In this paper I will focus on the first approach and develop a model for regulating the access price of a natural gas network under the assumption of information asymmetry.

1.2 Regulating a natural gas network

Gas from the Norwegian Continental Shelf (NCS) is a blend of wet gas and dry gas. Dry gas is commonly called natural gas and consists mainly of metan (CH_4). Natural gas has many characteristics that makes it preferable to other energy carriers like: flexibility in use and storage, high energy efficiency in power production and low omissions of polluting gases.

The value chains for natural gas can be divided into four steps: production, transmission, distribution and end use.

Production: Here the gas owner or licensee is the producer who extracts the gas from the ground.

Transmission: The transmitter or shipper transports gas in bulk through a transmission infrastructure from the area of production to the area of consumption. The infrastructure can consist of pipelines, tank lorries or ships.

Distribution: The distributor distributes gas from the connection point with the transmission infrastructure to the final consumers. Power plant and large industrial users of natural gas may bypass the distribution company and buy directly from a transmission company.

End use: The consumer is the final user of natural gas. The end user may be households, commercial consumers, large industrial users or power plants. A retail supplier of gas has to purchase it from the gas producers, move it through the transmission and distribution networks and sell it to final customers[3].

Figure 1 illustrates that transportation of natural gas can be done in different ways: as gas in pipelines, in liquid form (LNG) by tank lorries or ships or as compressed gas (CNG) by tankers or by pipelines. Figure 2 outlines the value chain for natural gas when the gas is transmitted in pipelines.

My focus in this paper is on regulation of the natural gas in pipelines. The existence of parallel transmission/distribution alternatives should however be taken into consideration when designing the optimal regulatory policy for natural gas pipelines.

The suppliers are the licensees of a gas field on the NCS represented by the operator. Once extracted, the gas is transmitted to one of three beachheads; Kollsnes, Kårstø and Tjeldbergodden[4]. Statoil is the major supplier of gas from the NCS; other important licensees are Hydro, Esso, Gaz de France, Conoco/Phillips, Shell and TotalFinaElf. Statoil is selling gas on all beachheads in Norway. It has been central in supplying gas to the distribution companies in Haugalandet and Bergen. Recently Shell has entered most new contracts with Norwegian gas distribution companies like Gasnor and Lyse Gass. In addition to Gasnor and Lyse Gass, many new regional distribution companies have been established like; Naturgass Trøndelag, Naturgass Grenland, Sogn og Fjordane Energi Gass, Naturgass Sør and Naturgass Møre. The technical solutions vary, some plan to invest in gas pipelines while most invest in infrastructure for LNG/CNG.

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[3] Note that the demand for gas is seasonal and stochastic. Thus any gas supplier needs mechanisms for coping with such demand variability. The gas can be stored in the gas field or in temporary storage facilities close to the market. An alternative is demand management. Prices can be set to dampen the variations in demand and/or the suppliers can offer contracts where the customers are prepared to have their supplies interrupted on peak demand days.

[4] Melkøya is a beachhead for LNG. Furthermore, there will be a new beachhead for natural gas at Aukra.

Figure 1

Different transmission solutions for natural gas

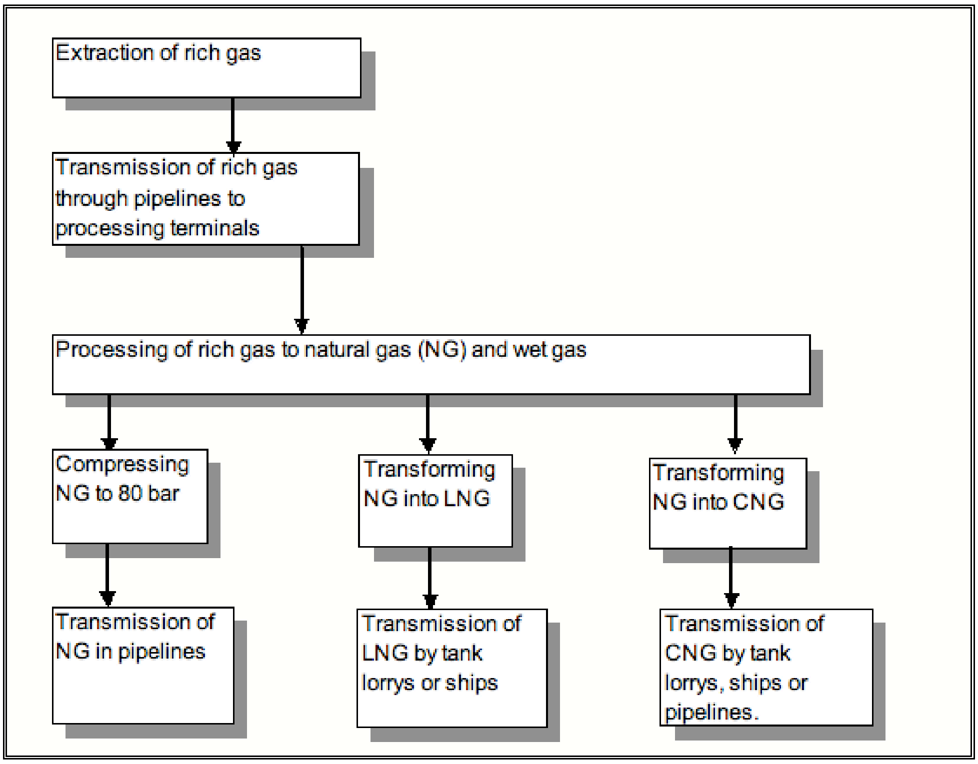
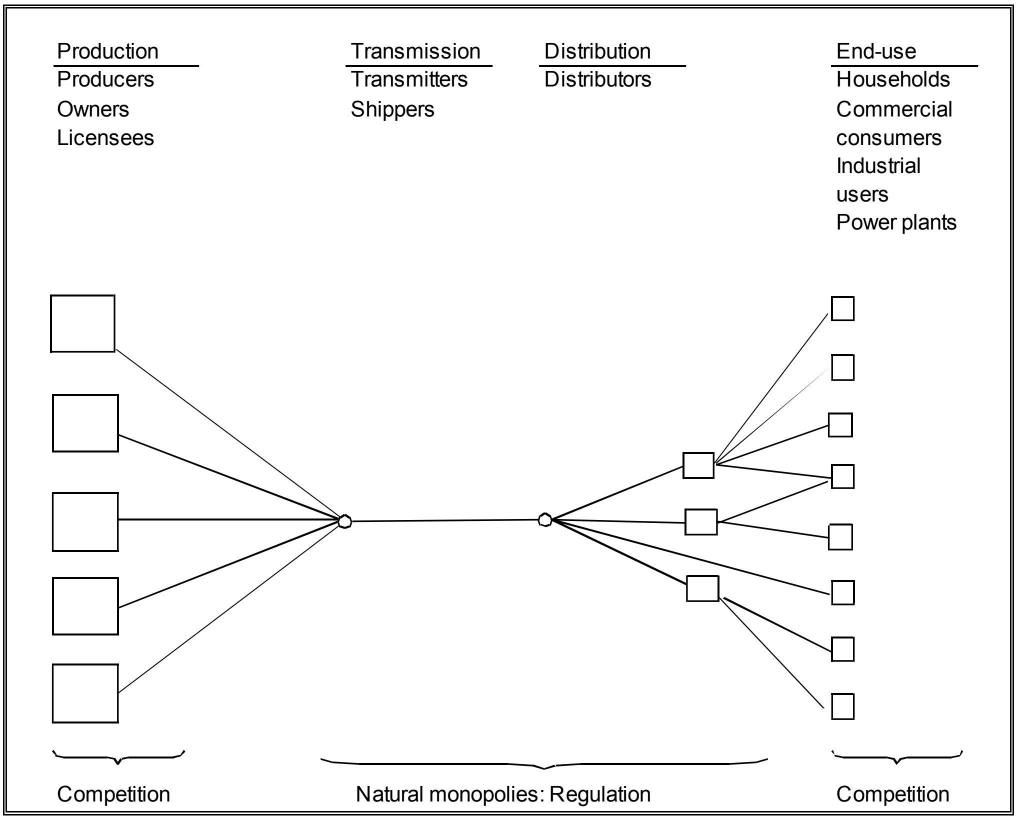


Figure 2

Value chain NG – transmission in pipelines



The value chain is at present highly vertically integrated. One example is Lyse Gass which buys gas from one of the operators, transports it through its own pipeline from Kårstø to Risvika and distributes the gas to its own customers. Another example is Gasnor which buys gas at Kollsnes, transforms the gas to LNG at its own LNG plant and transports the LNG to its customers on its own tankers. A third example is the establishment of LNG Norge as. This company, which is a subsidiary of Statoil, can become an important supplier of LNG in the retail market for natural gas.

While there may be scope for competition in the supplier[5] and end user market[6] for natural gas, transmission and distribution of natural gas are often characterized as *natural monopolies*. The expected life of a natural gas pipeline is well over 30 years and the investment required is often very large and sunk. This gives rise to a cost structure of falling unit cost in the transmitting industry (see figure 3). The transmission unit cost, calculated taking into account both investments and operating costs, is highly dependent on the utilization of the capacity in the pipeline. As a result, there is a case against allowing horizontal competition, although there might be an argument for allowing entrants to build new pipelines serving new customers[7].

Furthermore *hold-up problems* may lead to investment levels in natural gas pipelines below what is socially optimal. Both producers of natural gas, transmission and distribution companies and end user customers must undertake investments which are irreversible. This can lead to opportunistic behaviour by all participants. A producer of natural gas can f.ex. threat to delay the development of a gas field. If the threat is perceived as convincing,

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[5] Production is not naturally monopolistic. The marginal cost of extracted gas can be expected to rise over time because the most accessible fields are developed first. Once extracted, the gas is transmitted to the beachhead.

[6] Having access to the transportation network (or access to tankers if LNG/CNG) means that the supply of gas to final customers is potentially highly competitive. Sunk costs in supply are small. The main assets are working capital and contracts with producers and customers that can be resold.

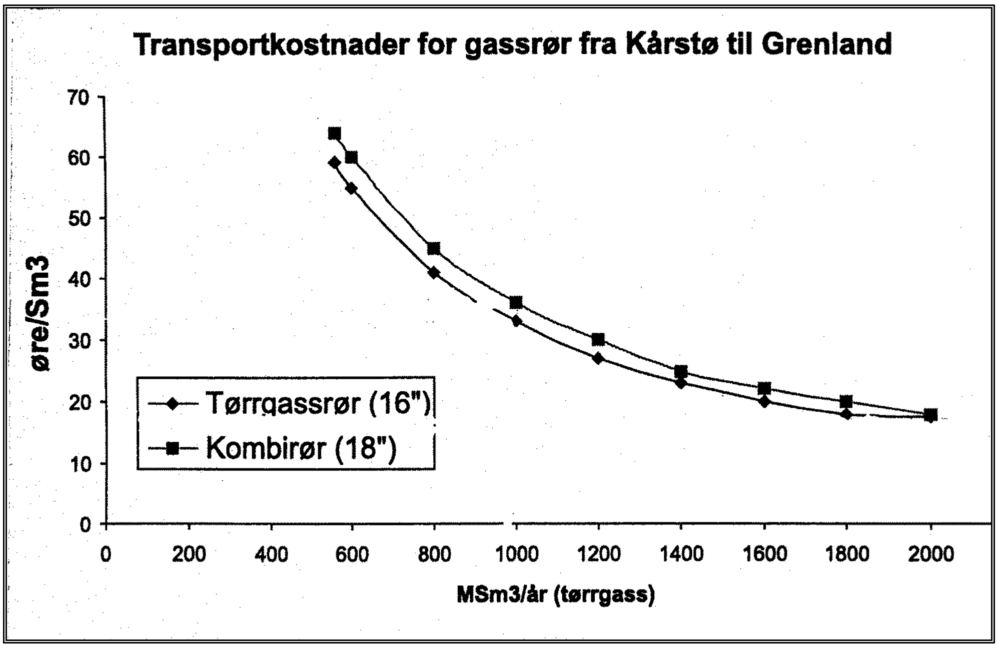
[7] A change in technology or rapid rise in demand might also make horizontal competition in transportation socially optimal.

the transmission company's best strategy can be to offer access unit charges which do not cover total costs including both investments and operating costs.

Figure 3

Estimated unit costs for natural gas pipelines from Kårstø to Grenland.

Source: St.meld. nr. 47 (2003-2004).



The problem of hold-up has in many countries been met by designing long-term "take-or-pay" contracts. The contract specifies that the producer or "shipper" must pay for his share of the capacity in the pipeline, whether he uses it or not. The tariff can be set equal to the average unit cost of the pipeline. However, if the producer/"shipper" cannot monitor the costs of operating the pipeline, the transmission company will have an incentive to claim that their costs are higher or their capacity utilization is lower than it actually is. Therefore a regulator is often given the authority to determine both the capacity charge and the variable costs due to transmission. The regulator must also approve the service contract and further network expansions/reductions.[8]

[8] The NEB Act (Canada) and the Natural Gas Act (USA) give no clear guiding rules as to how the transmission tariffs shall be determined, only that they shall be "reasonable and not

The hold-up problem is a result of the participants not having any outside opportunity. If however a producer of natural gas can transform the gas to liquid form, the market power of the transmission company will be reduced. Liquefied Natural Gas (LNG) is natural gas which is made liquid by lowering the temperature. The liquid gas can be stored and transported on a tank, and be transported by lorry, ship or train. LNG also offers distribution solutions with greater flexibility than pipelines, because one can alter the points for loading and unloading and because there is a second hand market for tank lorries, ships or storage tanks. A value chain for LNG consists of a production plant (inclusive shipping terminal), transporting units (ships, tank lorries, containers etc), terminals and installation for redistribution in tankers or low pressure pipelines. Also transforming natural gas to Compressed Natural Gas (CNG) represents an alternative to the producer. CNG is natural gas which is transported and stored under high pressure. CNG has many of the same merits as LNG. The market share of CNG is however much smaller than natural gas in pipelines and LNG. The cost structure of the three transportation alternatives are compared in figure 4. The relatively flat unit costs curves for LNG and CNG implies that investment in LNG/CNG infrastructure is not subject to economies of scale. There is no clear motive for regulating the income from the related infrastructure.

The choice of transportation alternative will depend on market size and transport distance. Investment in pipelines can be profitable compared to investment in infrastructure for LNG or CNG when volumes are high and/or transported distances are relatively small. In densely populated areas in Europe and in the US, transmission of gas is mainly through pipelines. Recently, there has been an increased interest in Liquefied Natural Gas (LNG) worldwide. According to St.meld. nr. 47 (2003-2004) Norway might experience a gradual development of domestic use of natural gas where LNG will be sold in an early

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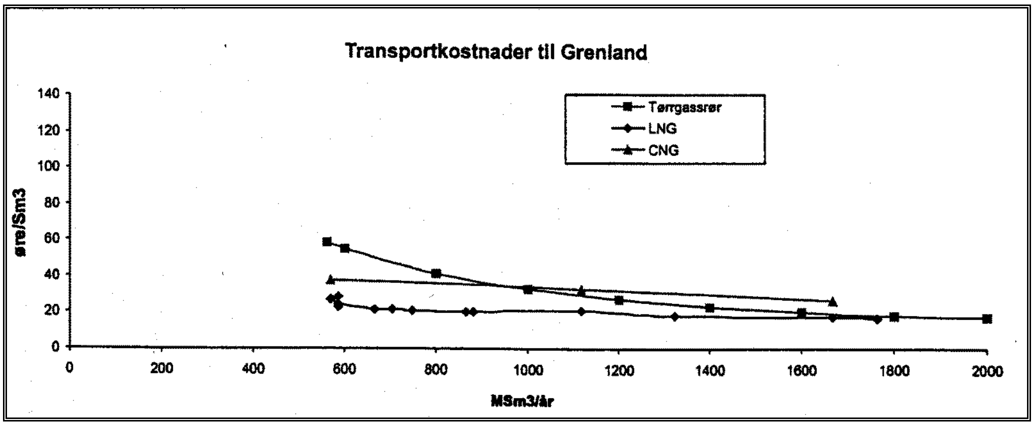
discriminatory". The regulators in both countries has however practised a cost of service regulation. Recently there has been an increased interest for, and use of, regulatory policies that are designed to give a higher incentive for cost reduction. An example is price cap regulation phase, while natural gas in pipelines will be sold if and when the market develops.

Figure 4

Transmission costs for natural gas in pipelines ("tørrgassrør"), LNG and CNG. Source: St.meld. nr. 47 (2003-2004).



In this paper I will focus on the regulation of income from transmission of gas in pipelines. I will take a partial perspective where I don't include the effects of competition between the various forms of natural gas.[9] I hope to broaden this perspective in my later work.

2 The normative model

2.1 Introduction

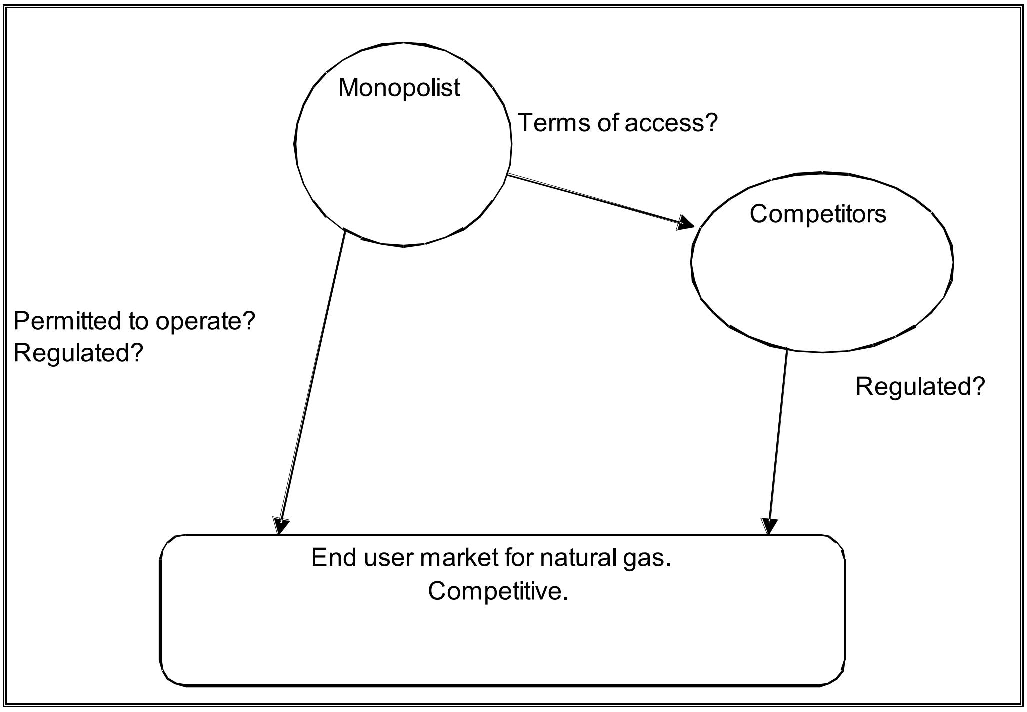
The value chain for natural gas includes networks with a cost structure characterized as natural monopoly. However, many activities which use the network as an output and input are potentially competitive (sale of gas from the producers, distribution of gas to end customer and generation of electricity). A central issue is therefore to combine the necessary regulation of the network with the organization of competition in those activities.

[9] Also, I don't include competition with other energy carriers that produce the same services for the end users. One example is the service heat. Electricity, different oil products and wet gas can provide the same service. They can be treated as close substitutes to natural gas in this respect.

The problems facing the Regulator can be visualized in figure 5 below. A monopolist owns the gas network. A group of small competitors sells natural gas in the retail market. I assume that the competitors are dependent on access to the gas network if they are to supply natural gas to their customers. Furthermore, I assume that the competitors provide the same good and that competition means that prices are reduced to their marginal costs. The central issue is on what terms should the competitive firms be given access to the monopolist network? The solution to this problem will depend on whether the monopolist has access to the competitive end user market and on whether the prices set by the regulator and/or the competitive fringe in this market is regulated.

Figure 5

Access pricing and competition in the retail market



When it comes to vertical integration two different types of policies can be observed: 1) divestiture and 2) defining access charges and letting the monopoly compete. An example of the first policy is found in the USA telephone industry where the local network monopolies have been prevented from entering the value added markets as well as the long distance market because of the Department of Justice's belief that it is impossible to define access rules to network which create fair competition in those markets. [10] In this paper however, I will concentrate on the current situation for the Norwegian gas industry where a gas company like Lyse Gass is allowed both to invest and operate a gas pipeline and be involved in other and competitive parts of the gas value chain. The regulatory issues are then reduced to setting the access prices and perhaps regulate the monopolist price in the retail market.

An overview of access pricing theory is given by Armstrong and Sappington (2003). Their presentation is however based upon an assumption of symmetric information. Laffont and Tirole (1994) develop a model for common network assuming asymmetric information[11]. They use the telecommunication sector as an example, but their model is general. With minor modifications, I have used their model to illustrate how optimal access prices could be derived for a natural gas network.

2.2 The assumptions

The model consists of a dominant firm which operates a network and sells natural gas (good 1) in the end user market and an unregulated competitive fringe which also sells natural gas (good 2) in the end user market. Good 1 and good 2 are close[12] substitutes. The competitive fringe requires access to the network (good 0) in order to reach their customers.

The dominant firms activities are split into two; the activities characterized by a natural monopolistic cost structure and the activities which are not.. The first group of activities are related to operating the network. The second group of activities comprise all activities that are potentially competitive. Examples are: negotiating and purchasing natural gas from the producers and entering new contracts with final customers. The cost structure is divided into two to reflect

[10] This example is from J.-J. Laffont and J. Tirole (1994).
[11] See also J.-J. Laffont and J. Tirole (1994), chapter 5.
[12] The quality of the goods sold are equal. The terms of the contract may however differ, and the customer may therefore view the goods as close but not perfect substitutes.

this division. I assume that the manager can exert cost reducing effort in both the monopolistic and the competitive part.

The basic assumptions of the model:

1. The model is static. The regulator acts like a Stackelberg leader and designs first the contract which the firms then react to.

2. The cost functions are given by:

   $C_0 = C_0\left(\overset{+}{\beta}, \overset{-}{e_0}, \overset{+}{Q}\right)$ monopoly operating the network

   $C_1 = C_1\left(\overset{+}{\beta}, \overset{-}{e_1}, \overset{+}{q_1}\right)$ monopoly producing good 1

   $C_2 = cq_2 + aq_2$ competitive fringe producing good 2

   where $Q = q_1 + q_2$ is the level of network activity, β is a productivity parameter and e_i are levels of nonmonetary effort.

3. Regulation is subject to adverse selection β and moral hazard e. The regulator knows however:

   $\beta \sim F(\beta) on \left[\underline{\beta}, \overline{\beta}\right] \quad f(\beta) > 0, \quad d\left[F(\beta)/f(\beta)\right]/d\beta \geq 0$

   $\psi\left(e_0 + e_1\right), \quad \psi' > 0, \quad \psi'' > 0, \quad \psi''' > 0$

4. $C_0, C_1, c, Q, q_1, q_2, a, p_1$ *and* p_2 are observable to the regulator. The regulator also knows the demand schedule of the three products.

5. The regulated firm and the competitive fringe's utility is given by the equations below. The regulated firm requires a nonnegative utility to sign a contract with the regulator. Competition will drive prices set by the competitive fringe down to its marginal costs. Because of constant marginal costs the fringe makes no profit, and therefore the social value of its profit is irrelevant.

$$U = t - \psi(e_0 + e_1) + aq_2$$
$$U \geq 0 \quad IRC$$

$$p_2 = c + a$$
$$\Rightarrow$$
$$\pi = p_2 q_2 - cq_2 - aq_2 = 0$$

6. The benevolent regulator acts as to maximize the total surplus of the consumers, the taxpayers and the firms:

$$S(q_1, q_2) - p_1 q_1 - p_2 q_2$$
$$- (1 + \lambda)(t + C_0 + C_1 - p_1 q_1) +$$
$$[t - \psi(e_0 + e_1) + aq_2] + (1 + \tilde{\lambda})[(p_2 - c - a)q_2]$$
$$where:$$
$$S(q_1, q_2), \quad S' > 0 \quad S'' < 0$$
$$\tilde{\lambda} = \alpha\lambda \quad \wedge \quad \alpha = [0,1]$$

7. Other assumptions are:
    - The regulator and the firms are risk neutral w.r.t. income.
    - The regulator can give the regulated firm a monetary transfer; t. The regulator faces a shadow cost of public funds; λ.
    - The regulator reimburses costs, receives directly the revenue from the sale of good 1 and pays a net transfer to the regulated firm. The regulated firm receives the access charges directly.

Some of the assumptions made are worth commenting:

The original model in the paper by J.-J. Laffont and J. Tirole (1994) includes good 0 both as an input to the production of good 1 and 2 and as a final monopoly good that can be sold in the end user market.[13] That does not seem suitable in the application of their model to the gas market. Furthermore, Laffont and Tirole assumes that all three prices are regulated. In contrast, I

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[13] In equation (1) Q is then $Q = q_0 + q_1 + q_2$ and equation (6) is altered to

$$S(q_0) + \tilde{S}(q_1, q_2) - p_0 q_0 - p_1 q_1 - p_2 q_2 - (1 + \lambda)(t + C_0 + C_1 - p_0 q_0 - p_1 q_1) +$$
$$[t - \psi(e_0 + e_1) + aq_2] + [(p_2 - c - a)q_2]$$

assume that p_1 and a are regulated, while p_2 is not. My model yields the same result, however, because the competitive fringe is assumed to be a price taker and faces a constant marginal cost.

The model assumes that the regulator sets both the access charge and the price level of the regulated firm. Arguing that the final market is potentially competitive, an alternative case could be to only regulate access prices.

I have assumed that the costs of operating the network and producing good 1 are separately observable. The realism of this assumption for the Norwegian gas market will have to be investigated before I go on refining the model. However, Laffont and Tirole (1994) investigate some conditions under which the observability of the sub cost functions is not necessary to develop a normative pricing rule.

The constant[14] marginal cost of producing good 2 is assumed known, which means that I refrain from analyzing incentive issues in the competitive fringe. If, in addition, the technologies of the dominant firm and the competitive fringe were correlated, the regulator could learn from the quantities traded information not contained in the regulated firm's choice of prices. If I want to study access pricing under asymmetric information, I must therefore assume that the technologies are not related. This does not seem to fit well with reality.

In this model the total cost of the competitive fringe varies linearly with the access unit charge a. This indirectly implies that the competitive fringe has no outside opportunity to use the network as an input[15]. The existence of LNG and CNG, might question the realism in this assumption.

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[14] If we instead assumed a strictly convex cost function, the competitive fringe would make a positive profit. The social value of this profit would have an effect on the access price (see equation 5.12 and 5.13 in Laffont and Tirole (1993))

[15] If such an alternative existed, we might have assumed a concave cost function where $\partial C_2 / \partial a < 0$.

Finally I have assumed that the regulated firm's unit cost of producing the network services demanded by the competitors is the same as that of producing the network services for internal consumption. An important feature of this model is then that the regulated firm cannot claim that the production of the intermediate good is costly in order to hurt its competitors without making a case against the production of its own final good. This might be a reasonable assumption as long as monopolists like Lyse Gass has spare capacity in their pipelines, and do not have to invest in expansions.

I have made the classical monotone hazard rate assumption. This is done to make sure that the first and second order condition for truth telling are necessary and sufficient conditions for optimum for concave welfare functions.

2.3 Information symmetry – the benchmark result

Under complete information a utilitarian regulator maximises the surplus of the consumers, taxpayers and the firms subject to the monopoly's individual rationality constraint and the competitive pricing behaviour of the fringe. Below I have set up the optimisation problem substituting away t .

Figure 6

Optimization Program I: Symmetric Information

$$\max_{U, p_1, a, e_0, e_1} W =$$
$$S(q_1(p_1,p_2), q_2(p_1,p_2)) + \lambda \cdot p_1 \cdot q_1(p_1,p_2) - p_2 \cdot q_2(p_1,p_2)$$
$$- [1+\lambda]\begin{bmatrix} \psi(e_0+e_1) - a \cdot q_2(p_1,p_2) + C_0(\beta, e_0, q_1(p_1,p_2) + q_2(p_1,p_2)) \\ + C_1(\beta, e_0, q_1(p_1,p_2)) \end{bmatrix}$$
$$+ [1+\tilde{\lambda}][p_2 - a - c] \cdot q_2(p_1,p_2) - \lambda \cdot U$$
$$s.t.$$
$$U = t - \psi(e_0+e_1) + a \cdot q_2(p_1,p_2) \geq 0 \quad IRC$$

In a situation with complete information the individual rationality constraint will bind. Since public funds are costly, U should be set equal to zero. Furthermore, competition forces the prices on good 2 down to its marginal cost and the price on good 2 will equal $a + c$. Substituting for U and a, the optimisation problem can be reformulated:

$$\underset{p_1, p_2, e_0, e_1}{Max W} = S\left(q_1(p_1,p_2), q_2(p_1,p_2)\right) + \lambda \cdot p_1 \cdot q_1(p_1,p_2) + \lambda \cdot p_2 \cdot q_2(p_1,p_2)$$
$$-[1+\lambda]\cdot\left[\begin{array}{l}\psi(e_0+e_1) + C_0\left(\beta, e_0, q_1(p_1,p_2) + q_2(p_1,p_2)\right)\\ + C_1\left(\beta, e_1, q_1(p_1,p_2) + c\cdot q_2(p_1,p_2)\right)\end{array}\right]$$

Assuming concave S and C_0 *and* C_1 convex in (e_0, e_1, q_1, Q), the optimal regulation is characterized by the following four first order conditions (see appendix A):

$$\frac{\partial W}{\partial p_1} = 0 \Rightarrow L_1 \equiv \frac{p_1 - C_{0Q} - C_{1q_1}}{p_1} = \frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_1},$$
$$\frac{\partial W}{\partial p_2} = 0 \Rightarrow L_2 \equiv \frac{p_2 - C_{0Q} - c}{p_2} = \frac{\lambda}{1+\lambda}\frac{1}{\hat{\eta}_2},$$
$$\frac{\partial W}{\partial e_0} = 0 \Rightarrow \psi'(e_0+e_1) = -C_{0e_0}$$
(1)
$$\frac{\partial W}{\partial e_1} = 0 \Rightarrow \psi'(e_0+e_1) = -C_{0e_1}$$
where:
$$\hat{\eta}_i = \eta_i \frac{\eta_i\eta_j - \eta_{ij}\eta_{ji}}{\eta_i\eta_j + \eta_i\eta_{ij}} < \eta_i,$$
$$\eta_i = -\frac{\partial q_i}{\partial p_i}\frac{p_i}{q_i}, \quad \eta_{ij} = \frac{\partial q_i}{\partial p_j}\frac{p_j}{q_i}, \quad j \neq i, \quad j = 1,2, \quad i = 1,2$$

As a consequence the access unit charge is given by the following formula:

$$a = p_2 - c = \frac{C_{0Q} + [\lambda/(1+\lambda)](c/\hat{\eta}_2)}{1 - [\lambda/(1+\lambda)](1/\hat{\eta}_2)}$$
(2)
$$L_0 = \frac{a - C_{0Q}}{a} = \frac{(C_{0Q} + c)[\lambda/(1+\lambda)](1/\hat{\eta}_2)}{C_{0Q} + [\lambda/(1+\lambda)](c/\hat{\eta}_2)}$$

The regulator should set prices in the regulated firm according to L_1 *and* L_0. Competition will secure prices on the unregulated good according to L_2.

Both the access unit charge and the price on good 1 are higher than the marginal costs of providing the goods. This is because deficits are socially costly[16]. Observing an external transfer price (a) in excess of the internal transfer price (C_{0Q}), is no evidence that the regulated firm has too much incentive to weaken competition, since this pricing formula has to hold even in the case where the regulator has full information about the firm.

Note in particular that the access price and the price level of the substitute goods exceeds not only the marginal cost of providing access but also the traditional Ramsey price $\lambda/(1+\lambda)\eta_i$ associated with good i's elasticity of demand. The key to understand this result is to view the access good and good 1 as substitutes. An increase in p_1 not only decreases the demand for good 1, it also raises the demand for good 2. The increased demand for good 2 raises the demand for the access good by an equal amount. A unit increase in q_2 therefore implies a gain of revenue from the network for the regulated firm. This dampening effect is included in the super elasticity for good 1 which is lower than good 1's elasticity of demand.

Finally, note that an alternative regulatory policy is to set an access charge equal to the marginal costs and levy a tax on good 2:

$$a = C_{0Q} \quad \Rightarrow \quad tax = \frac{\lambda}{1+\lambda}\frac{p_2}{\tilde{\eta}_2}$$

2.4 Information asymmetry – incentive issues

In the case of information asymmetry the regulator must design a mechanism Γ which consists of a strategy set for the agent, as well as an outcome function $g(\cdot): S \to X$. $\Gamma = (S, g(\cdot))$.

[16] If the deficit of the regulated firm could be financed by a lump sum tax, all prices would equal marginal costs.

According to the revelation principle, a necessary condition for a general mechanism to implement the social choice function is that it can be replaced by a direct mechanism where the firms are asked to announce their true type.

The regulator offers a direct mechanism to the regulated firm

$$\square = \{[\underline{\square}, \bar{\square}], \{(\tilde{\square}), C_0(\tilde{\square}), C_1(\tilde{\square}), q_1(\tilde{\square}), Q(\tilde{\square}), a(\tilde{\square})\}\}.$$

The firm announces its type; $\hat{\square}$. The firm will then receive a net transfer $t(\hat{\square})$ and is instructed to produce $q_1(\hat{\square})$ and transport $Q(\tilde{\square})$ at the sub costs $C_0(\hat{\square})$ *and* $C_1(\hat{\square})$ and charge an access unit price $a(\hat{\square})$.

We proceed to find under what conditions the firm will have as its equilibrium strategy to participate and truthfully reveal its identity. Let $E_0(\square, C_0, Q)$ be the solution in e_0 of $C_0(\square, e_0, Q)$ and let $E_1(\square, C_1, q_1)$ be the solution in e_1 of $C_1(\square, e_1, q_1)$, we can rewrite the objective function of the regulated firm as a function of the announced and the true productivity type

$$U(\square, \hat{\square}) = t(\tilde{\square}) + a(\tilde{\square})q_2(\tilde{\square}) \square\square \left(E_0(\square, C_0(\tilde{\square}), Q(\tilde{\square})) + E_1(\square, C_1(\tilde{\square}), q_1(\tilde{\square}))\right)$$

According to the revelation principle , the first order condition for the firm's maximisation problem should be satisfied when evaluated at $\tilde{\square} = \square$.

$$\left.\frac{\partial U(\square, \tilde{\square})}{\partial \tilde{\square}}\right|_{\tilde{\square}=\square} = U_2(\square, \square) = 0 \quad \square\square$$

Let $U(\square, \square) \equiv U(\square)$, we can replace this first order condition by

$$\dot{U}(\square) = \frac{dU(\square)}{d\square} = U_1(\square,\square) + U_2(\square,\square)\frac{d\tilde{\square}}{d\square} = U_1(\square,\square) =$$
$$\square\square\square(e_0 + e_1)\left(\frac{\partial E_0}{\partial \square} + \frac{\partial E_1}{\partial \square}\right) \square\square \; .$$

Since this expression is decreasing in beta and the utility is socially costly, the individual rationality constraint for the monopoly becomes

$$U(\bar{\square}) = 0\,.$$

Neglecting the second order condition (see appendix C), the regulator's optimisation program is given in figure 7:

Figure 7

Optimisation program II: Asymmetric information

$$
\begin{aligned}
& Max \int_{\underline{\square}}^{\bar{\square}} \{ S[q_1(p_1(\square), p_2(\square)), q_2(p_1(\square)), p_2(\square)] \\
& + \square[p_1(\square)q_1(p_1(\square), p_2(\square)) + p_2(\square)q_2(p_1(\square), p_2(\square))] \\
& \square(1+\square)\begin{bmatrix} \square(e_0(\square) + e_1(\square)) \\ + C_0(\square, e_0(\square), q_1(p_1(\square), p_2(\square)) + q_2(p_1(\square), p_2(\square))) \\ + C_1(\square, e_1(\square), q_1(p_1(\square), p_2(\square))) \\ + cq_2(p_1(\square), p_2(\square)) \end{bmatrix} \\
& \square\square U(\square) \} \cdot f(\square) \cdot d\square \\
& s.t. \\
& \dot{U}(\square) = \square\square\square(e_0 + e_1)\left(\frac{\partial E_0}{\partial \square} + \frac{\partial E_1}{\partial \square}\right) \\
& U(\bar{\square}) = 0
\end{aligned}
$$

I solve the optimisation problem using control theory (see appendix B). The resulting control variables are dependent on type and are given by equation (3) – (6).

(3)
$$L_1 \equiv \frac{p_1 - C_{0Q} - C_{1q_1}}{p_1} = \frac{\lambda}{1+\lambda}\frac{1}{\tilde{\eta}_1} + \frac{\lambda}{1+\lambda}\frac{F}{f}\frac{1}{p_1}\left[\frac{\partial}{\partial Q}\left(\frac{\partial E_0}{\partial \beta}\right) + \frac{\partial}{\partial q_1}\left(\frac{\partial E_1}{\partial \beta}\right)\right]$$

(4)
$$L_2 \equiv \frac{p_2 - C_{0Q} - c}{p_2} = \frac{\lambda}{1+\lambda}\frac{1}{\tilde{\eta}_2} + \frac{\lambda}{1+\lambda}\frac{F}{f}\frac{1}{p_2}\left[\frac{\partial}{\partial Q}\left(\frac{\partial E_0}{\partial \beta}\right)\right]$$

(5)
$$\psi'(e_0 + e_1) = -C_{0e_0} - \frac{\lambda F}{(1+\lambda)f}\left[\psi''(e_0 + e_1)\left(\frac{\partial E_0}{\partial \beta} + \frac{\partial E_1}{\partial \beta}\right) + \psi'(e_0 + e_1)\frac{\partial^2 E_0}{\partial \beta \partial C_0}C_{0e_0}\right]$$

(6)
$$\psi'(e_0 + e_1) = -C_{0e_1} - \frac{\lambda F}{(1+\lambda)f}\left[\psi''(e_0 + e_1)\left(\frac{\partial E_0}{\partial \beta} + \frac{\partial E_1}{\partial \beta}\right) + \psi'(e_0 + e_1)\frac{\partial^2 E_1}{\partial \beta \partial C_1}C_{1e_1}\right]$$

The optimal access charge is then

(7) $$a = p_2 - c = C_{0Q} + \frac{\lambda}{1+\lambda}\frac{p_2}{\tilde{\eta}_2} + \frac{\lambda}{1+\lambda}\frac{F}{f}\frac{\partial}{\partial Q}\left(\frac{\partial E_0}{\partial \beta}\right).$$

Under asymmetric information, all prices are modified by an incentive correction term. Analysing this term I note:

- There is no correction term for the most efficient type because $F(\underline{\beta})=0$. The correction terms for other types will depend on the sub cost functions.

- All prices depend on the sub cost function operating the network, while the price on the monopoly good also depends on the sub cost function producing good 1.

- The terms $\partial E_0 / \partial \beta = -C_{0\beta} / C_{0e_0}$ and $\partial E_1 / \partial \beta = -C_{1\beta} / C_{1e_1}$ is central in the incentive correction term. This is the rate at which the monopoly must substitute effort for loss of productivity to keep the same level of cost. Note that if $\partial^2 E_0 / \partial \beta \partial Q$ and $\partial^2 E_1 / \partial \beta \partial q_1$ are positive, an increase in the production of the goods raises monopoly's utility; $U(\beta) = \int_{\beta}^{\bar{\beta}} \psi'(\cdot)(\partial E_0 / \partial \beta + \partial E_1 / \partial \beta) d\beta$. Since the monopoly's utility is socially costly, the regulator will try to reduce the quantities produced. This can be achieved by raising the prices. To find the sign of the incentive correction term, we investigate what happens to these two terms as total output increases

    - If $C_0 = C_0(\beta_0(\beta, e_0), Q)$ and $C_1 = C_1(\beta_1(\beta, e_1), q_1)$, the incentive correction terms disappear. This is the famous dichotomy condition, under which prices do not serve any incentive purpose under asymmetric information.

    - Under more general cost functions, the effect of the incentive correction term is ambiguous. Assuming the "Spence-Mirrlees" condition on cost; $C_{0\beta Q} > 0$ *and* $C_{1\beta q_1}$, and assuming that increased effort decreases the marginal cost, the sign of the nominator of $\partial E_i / \partial \beta = -C_{i\beta} / C_{ie_i}$ is undetermined.

Under asymmetric information the optimal access price and the optimal price of good 1 can be both higher and lower than under symmetric information. This will depend on the sub cost functions of the regulated firm. With the assumption of common network, the regulated firm will have limited gains from exaggerating the marginal costs of giving access to competitors. As a result the marginal cost C_{oQ} and the incentive correction $\partial E_0^{\,2} / \partial \beta \partial Q$ affect the pricing of access and that of good 1 in qualitatively equivalent ways.

Equations (5) and (6) give the first order conditions for the effort levels under asymmetric information. The formulas are extended with an incentive correction term. This term is equal to zero for the most efficient type. The correction term will also disappear if we assume that the sub cost functions supports the dichotomy condition.

To sum up, the optimal regulatory policy under asymmetric information is given by:

- Equation (3) and (7) gives the optimal prices for every type $p_1^*(\beta)\, and\, a^*(\beta)\ \ \forall\beta,$

- Equation (5) and (6) gives the optimal effort for every type $e_0^*(\beta)\, and\, e_1^*(\beta)\ \ \forall\beta,$

- Substituting these optimal variables, into the cost functions we get the optimal cost levels for every type
$$C_0^*\left(\beta, e_0^*(\beta), q_1\left(p_1^*(\beta), p_2^*(\beta)\right) + q_2\left(p_1^*(\beta), p_2^*(\beta)\right)\right),$$
$$C_1^*\left(\beta, e_1^*(\beta), q_1\left(p_1^*(\beta), p_2^*(\beta)\right)\right)\ \ \forall\beta$$

- The utility level for every type is then given by
$$U^*(\beta)=\int_{\beta}^{\bar{\beta}} \psi'(e_0^*(\beta)+e_1^*(\beta))\{\frac{\partial E_0(\beta)}{\partial \beta}+\frac{\partial E_1(\beta)}{\partial \beta}\}d\beta\ \ \forall\beta,$$

- The net transfer for every type is finally given by
$$t^*(\beta)=U^*(\beta)+\psi\left(e_0^*(\beta)+e_1^*(\beta)\right)+a^*(\beta)q_2\left(p_1^*(\beta), p_2^*(\beta)\right)\ \ \forall\beta$$

2.5 A budget balanced model

When the government is prohibited from making transfers to the regulated firm, the regulators will maximise social welfare subject to a budget balance constraint. The shadow price of funding is now type contigent $\lambda(\beta)$. The optimal pricing and effort levels are changed as follows

$$\lambda/(1+\lambda) \;\rightarrow\; \lambda(\beta)/(1+\lambda(\beta)) \qquad \text{the Ramsey term (pricing)}$$

$$\frac{\lambda}{1+\lambda}\cdot\frac{F}{f} \;\rightarrow\; \frac{\int_{\underline{\beta}}^{\beta}\lambda(x)f(x)dx}{(1+\lambda(\beta))f(\beta)} \qquad \text{the incentive corr. term (pricing/effort)}$$

In particular the access pricing equation (7) becomes

$$(8) \qquad a = p_2 - c = C_{0Q} + \frac{\lambda(\beta)}{1+\lambda(\beta)}\frac{p_2}{\eta_2} + \frac{\int_{\underline{\beta}}^{\beta}\lambda(x)f(x)dx}{(1+\lambda(\beta))f(\beta)}\cdot\Phi'(e)\frac{\partial}{\partial Q}\left(\frac{C_{0\beta}}{C_{0e}}\right).$$

Note the similarities between this model and the model with government transfer. The network imposes fixed costs which cannot be financed by nondistortive lump sum taxes. By charging an access price above marginal cost, the financial burden of the regulator or the price distortion associated with the firms budget constraint are reduced.

On the other side, by giving up one regulatory instrument, the regulation becomes more complex and more inefficient as the regulator tries to use only access prices in order to meet various market structure goals.

3 The Efficient Component Pricing Rule

So far I have assumed the existence of a group of competitive firms in the retail market. The access price has then been set to achieve allocative efficiency. What happens when the regulator is also concerned with inducing proper entry (productive efficiency) and the only tool available to the regulator is the access price?

Ideally, the change in the social welfare due to a new competitor should be internalized in the competitors objective function. The competitor would then enter the market only if his investments and operating costs were less than the positive change in social welfare. The regulatory mechanism could include Ramsey prices to secure allocational efficiency and a subsidy that reflected the change in consumer surplus.

Alternatively, if the competitor does not face any fixed entrant and the cost functions are according to the dichotomy conditions, the regulator should set prices equal to the Ramsey price formulas developed in subsection 2.4 and 2.5.

Baumol (1993) has proposed a simple access pricing rule called the Efficient Component Pricing Rule (ECPR). According to market contestability theory the access charge should be set equal to the cost of access plus the incumbent's foregone profit caused by supplying a unit of access to its rivals[17].

(9) $$a = C_{0Q} + \left(p_1 - C_{0Q} - c_1\right) = p_1 - c_1 \quad \text{where} \quad c_1 = \partial C_1 / \partial q_1$$

I will now compare ECPR with the normative pricing rules derived in section 2.4 and 2.5 assuming balanced budget. Like before, I assume that gas supply from the monopoly and from the competitive fringe can be treated like imperfect substitutes. I will make use of the following sub cost functions

$$C_0 = H_0\left(\beta - e_0\right)\left(q_1 + q_2\right) \quad \text{where} \quad c_0 \equiv H_0\left(\beta - e_0\right) = C_o / \left(q_1 + q_2\right)$$
$$C_1 = H_1\left(\beta - e_1\right)q_1 \quad \text{where} \quad c_1 \equiv H_1\left(\beta - e_1\right) = C_1 / q_1$$

which implies constant marginal costs and that the dichotomy property hold.

The regulator maximises the expected social welfare subject to constraint (9), the incentives constraint and the balanced budget constraint. $t(\beta) = U(\beta) + \psi\left(e_0(\beta) + e_1(\beta)\right)$ can be interpreted as the firm's manager's

[17] See Baumol (1993): "If a component of a product is offered by a single supplier who also competes with others in offering the remaining product component, the single-supplier component's price should cover its incremental cost plus the opportunity cost incurred when a rival supplies the final product".

compensation and $p_2(\square) = p_1(\square) \square H_1(\square \square e_1) + c$ as a result of competition in the retail market and applying the ECP rule.

Figure 8

Optimization program III: Asymmetric information, no transfer and ECP access pricing rule.

$$
\begin{aligned}
& Max \int_{\underline{\square}}^{\overline{\square}} \{ S\left[q_1\left(p_1(\square), p_1(\square) \square H_1(\square \square e_1(\square)) + c\right), q_2\left(p_1(\square)\right), p_1(\square) \square H_1(\square \square e_1(\square)) + c\right] \\
& \square \square \begin{bmatrix} p_1(\square) \cdot q_1\left(p_1(\square), p_1(\square) \square H_1(\square \square e_1(\square)) + c\right) + \\ \left(p_1(\square) \square H_1(\square \square e_1(\square)) + c\right) \cdot q_2\left(p_1(\square), p_1(\square) \square H_1(\square \square e_1(\square)) + c\right) \end{bmatrix} \\
& + U(\square) \} \cdot f(\square) \cdot d\square \\
& s.t. \\
& \dot{U}(\square) = \square \square \square \left(e_0(\square) + e_1(\square)\right) \cdot 2 \\
& U(\overline{\square}) \geq 0 \\
& and \\
& p_1(\square) \cdot q_1\left(p_1(\square), p_1(\square) \square H_1(\square \square e_1(\square)) + c\right) \\
& + \left(p_1(\square) \square H_1(\square \square e_1(\square))\right) \cdot q_2\left(p_1(\square), p_1(\square) \square H_1(\square \square e_1(\square)) + c\right) \\
& \square H_0(\square \square e_0(\square)) \cdot \left(q_1\left(p_1(\square), p_1(\square) \square H_1(\square \square e_1(\square)) + c\right) + q_2\left(p_1(\square)\right), p_1(\square) \square H_1(\square \square e_1(\square)) + c\right) \\
& \square H_1(\square \square e_1(\square)) \cdot \left(q_1\left(p_1(\square), p_1(\square) \square H_1(\square \square e_1(\square)) + c\right)\right) \\
& = U(\square) + \square\left(e_0 + e_1\right)
\end{aligned}
$$

The resulting ECPR is given in equation (10) and should be compared to the optimal rule in equation (11).

(10)

$$
\begin{aligned}
& a(\square)^{ECP} = p_1(\square)^{ECP} \square c_1 = C_{0Q} + \frac{\square(\square)}{1 + \square(\square)} \cdot \frac{p_2}{\tilde{\square}_2^{ECP}} \\
& \tilde{\square}_2^{ECP} = \frac{p_2}{p_1} \cdot \frac{q_1}{q_1 + q_2} \square_1 + \frac{q_1}{q_1 + q_2} \square_2 \square \frac{p_2}{p_1} \cdot \frac{q_1}{q_1 + q_2} \square_{21} \square \frac{q_1}{q_1 + q_2} \square_{12}
\end{aligned}
$$

(11)

$$
\begin{aligned}
& a = C_{0Q} + \frac{\square(\square)}{1 + \square(\square)} \cdot \frac{p_2}{\tilde{\square}_2} \\
& \tilde{\square}_2 = \square_2 \frac{\square_1 \square_2 \square \square_{12} \square_{21}}{\square_1 \square_2 \square \square_2 \square_{21}}
\end{aligned}
$$

I will now compare the two pricing rules under different assumptions on marginal costs and demand.

Case I: Symmetric demands and costs:

In this case $\eta_1 = \eta_2$ and $c_1 = c$. The equality of the superelasticities implies that the Lerner indexes for good 1 and good 2 will be identical. Furthermore, the assumption of symmetric costs and competitive pricing implies equality of prices, so that

$$p_1 = p_2 \quad and \quad a = p_2 - c = p_1 - c_1 \ .$$

The normative pricing rules yield the same result as the ECP rule.

Case II: Linear demands, symmetric costs and captive customers.

I now assume that the monopoly has captive customers while competitors do not. This might be the case if the owner of the natural gas pipeline make long term take-or-pay contracts with customers in the retail market to avoid the hold-up problem discussed in section 1, while new entrants like f.ex. Gasnor involves in short-term contracts.

The assumptions in this case are

$$q_1 = a_1 - bp_1 + dp_2$$
$$q_2 = a_2 - bp_2 + dp_1 \quad with \quad d < b \; and \; a_2 < a_1 ,$$
$$and$$
$$c_1 = c$$

where $a_2 < a_1$ reflects that a higher part of the demand for the monopoly's good 1 is not responsive to price changes. Optimal pricing formulas now yield

$$p_1 > p_2 \quad and \quad a = p_2 - c < p_1 - c_1$$

The monopoly should optimally charge a higher prices than its competitors because a higher part of their demand is not price sensitive. The high mark-up on good 1 is then used as a subsidy on access charges.

Case III: Linear symmetric demands, cost superiority of monopoly.
Finally, I make use of the same demand functions as in case II except for $a_1 = a_2$. Furthermore I assume that $c_1 < c$. The optimal pricing formulas now yield

$$p_1 < p_2 \quad and \quad a = p_2 - c < p_1 - c_1$$

In this case the price differential in the retail market will only partially reflect the cost differential in producing good 1. The access price should optimally be set lower than the ECP rule to absorb the rest.

To sum up: under reasonable assumptions about the cost functions and the demand functions, the ECPR will in many situations suggest access prices that are higher than the normative pricing model.

4 Concluding remarks

In this paper I have tried to give a rather detailed description of the regulatory context for a new gas infrastructure in Norway. On this background I have presented an access pricing model developed by Laffont and Tirole (1994) and investigated how this model compares with ECPR developed by Baumol (1993). The model is developed for the Telecommunication sector, but seems to fit rather well with the regulatory context for gas infrastructure. My main objections to the application of this model is however:

- For a producer of natural gas there exists an outside opportunity to use the gas pipeline. Lets assume that the a gas company like Gasnor can choose between buying natural gas and transport it trough Lyse Gass' pipelines or transforming the natural gas to LNG and transport it by ship. The model should be altered to reflect this fact, by including a bypass mechanism in the model.

- The model does not include the producers profit function in the social welfare function. This can be acceptable if the producers are mainly foreigners and we set the weight on their profit equal to zero. Alternatively, if I assume a competitive market for sale of gas at the beachheads and a cost structure characterized by constant marginal costs, competition will result in zero profit.

- Finally, in this model I have treated natural gas supplied by the regulated firm (good 1) as an imperfect substitute to natural gas supplied by its unregulated competitors. Natural Gas is to a large extent a homogenous commodity with the required quality specified in the contracts. The differentiation of the products must then be due to different terms in the contracts and/or deliverance reliability[18].

In my further research I will try to develop an access pricing model for a vertically integrated gas company which competes with a competitive fringe in the downstream market and which competes with the LNG infrastructure in the upstream market. In doing so, I will model the competition in the producers market explicitly, and discuss to what extent the natural gas contracts can be viewed as close substitutes.

[18] This way of thinking is supported by Armstrong, Cowan and Vickers (1994) who says: “Since gas is a relatively homogenous commodity, price competition in supply is likely to be strong. Suppliers can, however, offer differentiated contracts to customers with variations in the degree of pass-through and in the extent of seasonal pricing.

APPENDIX A

The regulator will maximise the sum of consumer surplus, taxpayers surplus and firms utility subject to the monopoly's IRC and the competitive fringe's pricing behaviour.

$$\underset{p_1, p_2, e_0, e_1}{Max W} = S(q_1(p_1,p_2), q_2(p_1,p_2)) + \lambda \cdot p_1 \cdot q_1(p_1,p_2) + \lambda \cdot p_2 \cdot q_2(p_1,p_2)$$
$$- [1+\lambda] \cdot \begin{Bmatrix} \psi(e_0+e_1) + C_0(\beta, e_0, q_1(p_1,p_2) + q_2(p_1,p_2)) \\ + C_1(\beta, e_1, q_1(p_1,p_2) + c \cdot q_2(p_1,p_2)) \end{Bmatrix}$$

The marginal disutility in operating the network and producing good 1 shall both be equal to the marginal cost savings due to effort

$$\frac{\partial}{\partial e_0} = 0 \quad \Rightarrow \quad -[1+\lambda][\psi'(e_0+e_1) - C_{0e_0}] = 0 \quad \psi'(e_0+e_1) = -C_{0e_0}$$
$$\frac{\partial}{\partial e_1} = 0 \quad \Rightarrow \quad -[1+\lambda][\psi'(e_0+e_1) - C_{0e_1}] = 0 \quad \psi'(e_0+e_1) = -C_{0e_1}$$

Solving for optimal prices we have to take correctly account of the interdependencies between the two products in the demand functions. Noting that $\partial S / \partial q_i = p_i$ we get

$$\frac{\partial}{\partial p_1} = 0$$
$$(1+\lambda)\frac{\partial q_1}{\partial p_1}(p_1 - C_{0Q} - C_{1q_1}) + (1+\lambda)\frac{\partial q_2}{\partial p_1}(p_2 - C_{0Q} - c) = -\lambda q_1$$
$$\frac{\partial}{\partial p_2} = 0$$
$$(1+\lambda)\frac{\partial q_1}{\partial p_2}(p_1 - C_{0Q} - C_{1q_1}) + (1+\lambda)\frac{\partial q_2}{\partial p_2}(p_2 - C_{0Q} - c) = -\lambda q_2$$

These two equations can be rewritten using matrix notations

$$(1+\lambda)\begin{bmatrix} \frac{\partial q_1}{\partial p_1} & \frac{\partial q_2}{\partial p_1} \\ \frac{\partial q_1}{\partial p_2} & \frac{\partial q_2}{\partial p_2} \end{bmatrix} \begin{bmatrix} p_1 - C_{0Q} - C_{1q_1} \\ p_1 - C_{0Q} - c \end{bmatrix} = \begin{bmatrix} -\lambda q_1 \\ -\lambda q_2 \end{bmatrix}$$

or by Cramer's rule

$$p_1 \square C_{0q} \square C_{1q_1} = \square\left(\frac{\square}{1+\square}\right)\cdot \frac{\begin{vmatrix} q_1 & \dfrac{\partial q_2}{\partial p_1} \\ q_2 & \dfrac{\partial q_2}{\partial p_2}\end{vmatrix}}{\begin{vmatrix} \dfrac{\partial q_1}{\partial p_1} & \dfrac{\partial q_2}{\partial p_1} \\ \dfrac{\partial q_1}{\partial p_2} & \dfrac{\partial q_2}{\partial p_2}\end{vmatrix}}$$

$$\Updownarrow$$

$$L_1 \equiv \frac{p_1 \square C_{0q} \square C_{1q_1}}{p_1}$$

$$= \square\left(\frac{\square}{1+\square}\right)\cdot \frac{q_1 \dfrac{\partial q_2}{\partial p_2} \square q_2 \dfrac{\partial q_2}{\partial p_2}}{p_1 \left(\dfrac{\partial q_1}{\partial p_1}\dfrac{\partial q_2}{\partial p_2} \square \dfrac{\partial q_1}{\partial p_2}\dfrac{\partial q_2}{\partial p_2}\right)}$$

$$= \left(\frac{\square}{1+\square}\right)\frac{1}{\square_1}\cdot \frac{\square_1\square_2 + \dfrac{p_2 q_2}{p_1 q_1}\square_{2,1}\square_1}{\square_1\square_2 \square \square_{1,2}\square_{2,1}} = \left(\frac{\square}{1+\square}\right)\frac{1}{\square_1}\cdot \frac{\square_1\square_2 + \square_{1,2}\square_1}{\square_1\square_2 \square \square_{1,2}\square_{2,1}}$$

where:

$$\square_{i,j} = \frac{\partial q_i}{\partial p_j}\frac{p_j}{q_i} \quad \square \quad \frac{\partial q_i}{\partial p_j} = \square_{i,j}\cdot\frac{q_j}{p_i} \quad i,j = \{1,2\}$$

$$\square_{i,} = \square\frac{\partial q_i}{\partial p_i}\frac{p_i}{q_i} \quad \square \quad \frac{\partial q_i}{\partial p_i} = \square\square_{ij}\cdot\frac{q_i}{p_i} \quad i = \{1,2\}$$

making use of:

$$\frac{\partial q_2}{\partial p_1} = \frac{\partial q_1}{\partial p_2} \quad \square \quad \frac{p_2 q_2}{p_1 q_1}\square_{2,1} = \square_{1,2}$$

A symmetric expression can be obtained for L_2.

APPENDIX B

Under asymmetric information we find the optimal regulation from maximisation , subject to (3) and (4), of expected social welfare

$$
\begin{aligned}
\int_{\underline{\theta}}^{\bar{\theta}} & \{S[q_1(p_1(\theta), p_2(\theta)), q_2(p_1(\theta), p_2(\theta))] \\
& + \lambda[p_1(\theta) q_1(p_1(\theta), p_2(\theta)) + p_2(\theta) q_2(p_1(\theta), p_2(\theta))] \\
& - (1+\lambda)\begin{bmatrix} \psi(e_0(\theta) + e_1(\theta)) \\ + C_0(\theta, e_0(\theta), q_1(p_1(\theta), p_2(\theta)) + q_2(p_1(\theta), p_2(\theta))) \\ + C_1(\theta, e_1(\theta), q_1(p_1(\theta), p_2(\theta))) \\ + c q_2(p_1(\theta), p_2(\theta)) \end{bmatrix} \\
& - \lambda U(\theta)\} \cdot f(\theta) \cdot d\theta
\end{aligned}
$$

Here we have assumed:

- Concave S and convex sub cost functions
- SOC of truthful revealing is satisfied

I solve the optimisation problem using control theory. Let $\mu(\theta)$ be the co state variable, $U(\theta)$ the state variable and p_1, p_2, e_0 *and* e_1 the control variables, we can set the Hamiltonian equal to

$$
\begin{aligned}
H = & \{S[q_1(p_1(\theta), p_2(\theta)), q_2(p_1(\theta), p_2(\theta))] \\
& + \lambda[p_1(\theta) q_1(p_1(\theta), p_2(\theta)) + p_2(\theta) q_2(p_1(\theta), p_2(\theta))] \\
& - (1+\lambda)\begin{bmatrix} \psi(e_0(\theta) + e_1(\theta)) \\ + C_0(\theta, e_0(\theta), q_1(p_1(\theta), p_2(\theta)) + q_2(p_1(\theta), p_2(\theta))) \\ + C_1(\theta, e_1(\theta), q_1(p_1(\theta), p_2(\theta))) \\ + c q_2(p_1(\theta), p_2(\theta)) \end{bmatrix} \\
& + \lambda U(\theta)\} \cdot f(\theta) \\
& - \mu(\theta) \psi'(e_0 + e_1)\{\frac{\partial E_0}{\partial \theta}\{\theta, C_0(\theta, e_0(\theta), q_1(p_1(\theta), p_2(\theta)) + q_2(p_1(\theta), p_2(\theta))), \\
& q_1(p_1(\theta), p_2(\theta)) + q_2(p_1(\theta), p_2(\theta))\} + \frac{\partial E_1}{\partial \theta}\{\theta, C_1(\theta, e_1(\theta), q_1(p_1(\theta), p_2(\theta))), \\
& q_1(p_1(\theta), p_2(\theta))\}\}
\end{aligned}
$$

In optimum the following conditions must hold

(a) $$\frac{\partial H}{\partial p_1} = \frac{\partial H}{\partial p_2} = \frac{\partial H}{\partial e_0} = \frac{\partial H}{\partial e_1} = 0$$

(b) $$\square(\square) = \square\frac{\partial H}{\partial U} = \square \cdot f(\square)$$ Pontryagin condition

(c) $$\square(\underline{\square}) = 0$$ Transversality condition

Noting that the Hamiltonian is concave in U, p_1, p_2, e_0 *and* e_1, condition (a) and (b) is necessary and sufficient condition for optimum. The resulting control variable are dependent on type and is given by equation (d) – (g).

(d)
$$L_1 \equiv \frac{p_1 \square C_{=Q} \square C_{1q_1}}{p_1} = \frac{\square}{1+\square}\frac{1}{\tilde{\square}_1} +$$
$$\frac{\square}{1+\square}\frac{F}{f}\frac{\square}{p_1}\left[\frac{\partial}{\partial Q}\left(\square\frac{C_{0\square}(\square, e_0, Q)}{C_{0e_0}(\square, e_0, Q)}\right) + \frac{\partial}{\partial q_1}\left(\square\frac{C_{1\square}(\square, e_1, q_1)}{C_{1e_1}(\square, e_1, q_1)}\right)\right]$$

(e)
$$L_2 \equiv \frac{p_2 \square C_{0Q} \square c}{p_2} = \frac{\square}{1+\square}\frac{1}{\tilde{\square}_2} +$$
$$\frac{\square}{1+\square}\frac{F}{f}\frac{\square}{p_2}\left[\frac{\partial}{\partial Q}\left(\square\frac{C_{0\square}(\square, e_0, Q)}{C_{0e_0}(\square, e_0, Q)}\right)\right]$$

(f)
$$\square\square(e_0 + e_1) = \square C_{0e_0}$$
$$\square\frac{2\square F}{(1+\square)f}\left[\square\square(e_0 + e_1)\left(\frac{\partial E_0}{\partial \square} + \frac{\partial E_1}{\partial \square}\right) + \square\square(e_0 + e_1)\frac{\partial^2 E_0}{\partial \square \partial C_0} C_{0e_0}\right]$$

(g)
$$\square\square(e_0 + e_1) = \square C_{0e_1}$$
$$\square\frac{2\square F}{(1+\square)f}\left[\square\square(e_0 + e_1)\left(\frac{\partial E_0}{\partial \square} + \frac{\partial E_1}{\partial \square}\right) + \square\square(e_0 + e_1)\frac{\partial^2 E_1}{\partial \square \partial C_1} C_{1e_1}\right]$$

Finally I will rewrite condition (f) and (g) using C_k as the control variable

$$\frac{\partial H}{\partial C_k} = \square(1+\square)\square\square\,\square(\cdot)\frac{\partial E_k}{\partial C_k} + 1\square \cdot f\ \square\,\square F\,\square\,\square\,\frac{\partial E_k}{\partial C_k}\frac{\partial\left(E_0 + E_1\right)}{\partial\square} + \square\,\square\,\frac{\partial^2\left(E_0 + E_1\right)}{\partial\square\partial C_k}\square = 0$$

$$\Updownarrow$$

$$\square(1+\square)\cdot\square\,\square\, f + \square\cdot F\cdot\square\,\square\,\frac{\partial\left(E_0 + E_1\right)}{\partial\square}\square\cdot\square\frac{\partial E_k}{\partial C_k} = (1+\square)\cdot f + \square\cdot F\cdot\square\,\square\,\frac{\partial^r E_k}{\partial\square\partial C_k}$$

APPENDIX C

Under asymmetric information both the first order and the second order condition for the firm's maximisation problem should be satisfied when evaluated at $\tilde{\square} = \square$. The second order condition for truthful revelation is given by

$$\left.\frac{\partial U^2\left(\square,\tilde{\square}\right)}{\partial \tilde{\square}^2}\right|_{\tilde{\square}=\square} = U_{22}\left(\square,\square\right)$$

I assume the following sub cost functions

$$C_0 = \left(\square \square e_0\right)\cdot\left(q_1 + q_2\right) \quad \square \quad E_0 = \square \square \left(\frac{C_0}{q_1 + q_2}\right).$$

$$C_1 = \left(\square \square e_1\right)\cdot q_1 \quad \square \quad E_1 = \square \square \frac{C_1}{q_1}$$

Both sub cost functions can be inverted since they are monotonically increasing in $\square \square e_i$ *for* $i = 0{,}1$. Assuming the net transfer includes the access charge, the utility of the regulated firm can then be rewritten

$$U\left(\square\right) = t\left(\square\right) \square \square \left[2\square \square \left(\frac{C_0}{q_1 + q_2}\right) \square \left(\frac{C_1}{q_1}\right)\right].$$

The second order condition of incentive compatibility is then.

$$U_{22}\left(\square,\square\right) = \square U_{21}\left(\square,\square\right) = \square U_{21}\left(\square,\square\right) \square 0$$

$$\Updownarrow$$

$$U_{12}\left(\square,\square\right) = \partial\left(\square \square \square(\cdot)\cdot 2\right)/\partial\hat{\square}\Big|_{\hat{\square}=\square} = \square \square \square(\cdot)\cdot 2\cdot \partial\left[2\square \square \left(\frac{C_0\left(\hat{\square}\right)}{q_1 + q_2}\right) \square \left(\frac{C_1\left(\hat{\square}\right)}{q_1}\right)\right]/\partial\hat{\square}\Big|_{\hat{\square}=\square} \geq 0$$

$$\Updownarrow$$

$$\partial\left[\left(\frac{C_0^*\left(\square\right)}{q_1 + q_2}\right) + \left(\frac{C_1^*\left(\square\right)}{q_1}\right)\right]/\partial\square \geq 0$$

A necessary condition for optimum is then that the sum of effort is nonincreasing with type, or equivalently that the sum of average cost is nondecreasing with type.

REFERENCES

ARMSTRONG, M., S. COWAN, AND J. VICKERS (1994): *Regulatory Reform: Economic Analysis and British Experience.* MIT Press, Cambridge, MA.

ARMSTRONG, M. AND D. SAPPINGTON (2003): "Recent Developments in the Theory of Regulation", draft of a chapter to forthcoming Handbook of Industrial Organization (Vol. III).

BAUMOL, W. J. (1993): "Deregulation and Residual Regulation of Local Telephone Service", *AEI Studies in Telecommunications Deregulation* (American Enterprise Institute for Public Policy Research, New York University, New York).

LAFFONT, J-J. (1994): "The New Economics of Regulation Ten Years After", *Econometrica,* 62, pp 507-37.

LAFFONT, J-J. AND J. TIROLE (1993): *A Theory of Incentives in Procurement and Regulation.* Massachusetts Institute of Technology.

LAFFONT, J-J. AND J. TIROLE (1994): "Access pricing and competition", *European Economic Review*, 38(9), 1673-1710.

HOPE, E. (2000): *Studier i markedsbasert kraftomsetning og regulering*. Fagbokforlaget.

St. meld. Nr. 9 (2002-2003). Om innenlands bruk av naturgass mv.

St.meld. nr. 47 (2003-2004). Om innovasjonsverksemda for miljøvennlege gasskraftteknologiar mv.