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policy for a natural gas grid**

**by**

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# Investment mechanism design and public policy for a natural gas grid

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**Abstract:** This paper discusses how the government can design investment mechanisms to induce a socially optimal capacity increase in a gas grid that is owned by a syndicate of gas producers. Designing the investment mechanisms, the government has to take account of stepwise investment and asymmetric information of the network owners' willingness to pay for a capacity increase. We show that investment mechanisms allocating capacity based on the principle of Vickrey's second-price auction combined with regulated tariffs equal to marginal costs would be preferable. However, setting higher tariffs may reduce the problems associated with coalitional manipulation, voluntary participation and open access and nondiscriminatory prices.

# 1 Introduction

Norway is a major producer of natural gas in the European gas market. On the Norwegian continental shelf there are several companies producing gas on separate gas fields. A small part of the production is used domestically and mainly for industrial purposes. Therefore, the national interests in the gas sector are almost completely aligned with export interests. The gas producers have to transport the natural gas through the Norwegian gas grid to reach their downstream customers on the continent. In Norway, the EU directives in natural gas markets have induced a reorganization of the gas transmission network. In compliance with the EU directives, the selling and transportation roles have been separated. Therefore, the network has been reorganized as a syndicate consisting of the majority of gas producers on the Norwegian continental shelf, and an independent system operator has been established with assignment of transportation rights as one of its main tasks.

The network owners have to make collective investment decisions as to whether and how to expand their transportation capacity by new pipelines or new compressors increasing the pressure in the existing grid. Investment in a new pipeline or a new compressor may be seen as a stepwise investment. If the owners have information about all the producer benefits from an expansion, the investment decision is in principle trivial. However, with asymmetric information, free rider problems may occur. Therefore, it is important to design a mechanism inducing each owner to reveal his true willingness to pay for an expansion. If every producer reports truthfully, it would be easier to compare the benefits with the costs so that the transportation capacity can be expanded in an optimal way.

Rules for access to the upstream pipeline network are given by the government. The governing principle for access is that it has to be given to natural gas undertakings and eligible customers. Shippers with a duly substantiated reasonable need have right to access on objective and nondiscriminatory terms. Given the capacity of the gas transportation system and the regulated transportation tariff, a gas producer chooses his optimal gas transportation volume. If the capacity becomes scarce, there has to be rationing to equalize the demand to the transportation capacity. According to the present allocation rules the members of the syndicates of producers have priority in booking transport capacity up to 200% of their owner share in the gas grid.

In the existing Norwegian system for capacity expansion in the gas grid, the network owners report their demands for additional capacity to the government. The government decides whether to undertake a stepwise investment based on the sum of the individually reported demands. The investment costs are shared among the network owners according to their demands for additional capacity units. The ownership structure in the syndicate is adjusted to take into account the share of the investment costs each network owner has paid because of the capacity increase. Therefore, a new investment is included in the regulated tariff, which is given by a rate of 7 % of the syndicate's investment costs.

Most of the literature on this topic discusses optimal access prices with the objective to improve economic efficiency in the short run. There is an extensive literature on optimal access pricing, see e.g., Laffont and Tirole (1994). Cremer and Laffont (2002) as well as Cremer, Gasmi and Laffont (2003) discussed optimal access pricing in the natural gas pipeline sector. Cremer, Gasmi and Laffont examined optimal tariffs in a competitive market, while Cremer and Laffont discussed pricing of transportation of gas under perfect as well as imperfect competition. Hagen, Kind and Sannarnes (2007) discussed optimal tariffs in the case where the transport facilities are owned entirely by a national gas producer possibly with some public ownership share. Of these papers only Cremer and Laffont and Cremer, Gasmi and Laffont analyzed the investment decision together with the issue of optimal access prices. Generally, there has been a concern that the regulatory regime of the transportation system has focused too much on short-term efficiency issues and less on the incentives to invest in new and to upgrade the existing gas pipelines. In this paper, we primarily focus on the latter issue.

More precisely, we discuss how the government should design investment mechanisms to induce a socially optimal capacity increase in a gas grid that is owned by a syndicate of gas producers. In contrast to Cremer, Gasmi and Laffont (2003) we focus on stepwise investment decisions of a syndicate of gas producers where the network owners have private information about their willingness to pay for the additional capacity. We discuss incentive mechanisms that reveal the network owners willingness to pay for a capacity expansion and how these mechanisms are interacting with regulatory regimes and affects both short-term and long-term efficiency. We also discuss how a linear tariff paid for transportation of gas may be combined with a fixed cost for participating in the syndicate and how it affects the preferable linear tariff under which a third party may have access to the network at the same

linear tariff that the network owners are paying. An optimal investment mechanism depends both on whether the gas grid is congested or not after the expansion, and if it is possible to exclude the network owners from using the increased capacity.

The major insight of this paper is that investment mechanisms allocating capacity based on the principles of Vickrey's second-price auction combined with regulated tariffs equal to marginal costs will be preferable. This is because of the fact that these investment mechanisms reveal the network owners' willingness to pay and ensure that only the investments that are profitable for the syndicate are undertaken. A regulated tariff equal to marginal cost ensures short-term efficiency.

In section 2, we develop a simplified economic model for analyzing these issues. Because of stepwise expansion of the gas grid, the capacity increase can be larger or smaller than the excess transportation demand of the gas producers. In section 3, we compare the optimal expansion problem to that of an investment in a nonexcludable public good. Although expanded capacity in a pipeline may produce externalities, it may be possible to measure the increased transport capacity in the grid. In sections 4 and 5, we assume that this is possible and that the syndicate can decide to exclude some of the members from using the capacity increase. We discuss this both in the case where the capacity increase is so large that the users are nonrivalrous, section 4, as well in the case where the capacity is still congested after the expansion, section 5. Section 6 briefly concludes.

## 2 The model

We shall consider the case where the transportation infrastructure is owned by a syndicate of gas producers such as in the Norwegian Gassled. We make the model as simple as possible by setting the number of gas producers participating in the syndicate to 2, and we index them by  $i = 1, 2$ . They consider expansion of the network capacity in order to increase the flow of gas through the gas pipeline system. The network capacity can be increased by increasing the pressure through installing a costly compressor or by investing in new pipelines. We assume that both new pipelines and large compressors are stepwise investments. For simplicity, we assume that demand and cost conditions after an investment is undertaken do not vary between periods.

In other words, all periods are identical and the representative period is just replicated. Given the tariff and the capacity, the network owners maximize their individual profits.

We assume that there is also a gas producer without any transportation infrastructure of its own, and which depends on access to the established network in order to market its gas. The nonfacility based producer is domestically owned and will be referred to as the third party, denoted by the subscript  $T$ . The network owners and the third party compete in perfectly competitive downstream markets, where their gas prices are given by  $p_1, p_2, p_T$  for network owner 1, network owner 2 and the third party, respectively. In this model, the tariff scheme is the same for both the network owners and the third party. The network owners and the third party have to pay a linear tariff,  $\tau$ , per unit of transported gas in a period. The income to the syndicate from the gas transported in a period is given by  $\tau(x_1 + x_2 + x_T)$ , where  $x_1, x_2, x_T$  are the transported volumes of network owner 1, network owner 2 and the third party, respectively. Network owner  $i$ 's part of the syndicate's tariff income is denoted by  $\alpha_i \tau(x_1 + x_2 + x_T)$ , where  $\alpha_i$  is member  $i$ 's share in the syndicate.

If not explicitly stated otherwise, we assume that each network owner will pay a pro rata share of the costs of the investment, equal to his owner share,  $\alpha_i$ , in the syndicate. In addition to the investment costs, an owner  $i$  is committed to pay an amount of money  $T_i$ , which could be positive or negative. This payment depends on the mechanism used in the syndicate to ensure truthful revelation of demands for additional transportation capacity, which is necessary for an optimal investment rule.

The activity-related costs in the gas sector consist of two parts. The first part, to be denoted  $c_i^a(x_i)$ , measures the costs of gas extraction and of accessing the transportation pipeline.<sup>1</sup> This term depends solely on the producer's own volume. We assume that  $\partial c_i^a / \partial x_i > 0$  and  $\partial^2 c_i^a / (\partial x_i)^2 > 0$ ; i.e., there is increasing cost to scale in gas extraction. The other part is the transportation cost, which may depend on the transported volumes of the other network owners, and will be denoted  $c_i^t(x_1, x_2, x_T)$ . Total transportation costs in a period are therefore equal to  $C^t(x_1, x_2, x_T) = c_1^t(x_1, x_2, x_T) + c_2^t(x_1, x_2, x_T) + c_T^t(x_1, x_2, x_T)$ . This means that the marginal cost of transporting company

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<sup>1</sup>The part of the costs,  $c_i^a(x_i)$ , could alternatively be seen as an alternative cost of using the gas, i. e. the value of the gas transported by boat as liquefied gas to other downstream markets or the value of the gas stored and sold at a later point in time.

1's gas in a period is  $MC_1^t = \partial C^t / \partial x_1 = \partial c_1^t / \partial x_1 + \partial c_2^t / \partial x_1 + \partial c_T^t / \partial x_1$ . The term  $\partial c_2^t / \partial x_1 + \partial c_T^t / \partial x_1$  may be interpreted as a cost externality. This externality may for instance be because of the fact that it is necessary to increase the pressure if too much gas is fed into the pipeline, which depends on the total volume transported. This will increase the marginal costs of transporting gas for all producers. We therefore assume that  $\partial C_i^t / \partial x_i > 0$  and  $\partial^2 C_i^t / (\partial x_i)^2 > 0$  and that  $\partial C_T^t / \partial x_T > 0$  and  $\partial^2 C_T^t / (\partial x_T)^2 > 0$ . The costs to the syndicate of gas transportation in a period incurred by owner  $i$  is denoted by  $\alpha_i C^t(x_1, x_2, x_T)$ .

The capacity of the transportation infrastructure is given by  $x^K$ , which is set up at a cost (per period) of  $C^K(x^K)$ .<sup>2</sup> In the short run, a network owner maximizes his profits,  $\pi_i$ , for given capacity limit  $x^K$

$$\pi_i = p_i x_i - c_i^a(x_i) - \tau x_i + \alpha_i (\tau(x_1 + x_2 + x_T) - C^t(x_1, x_2, x_T)) - \alpha_i C^K(x^K) - T_i \quad (1)$$

In the long run,  $x^K$  also becomes a choice variable. Investments in new pipelines and compressors are assumed to be stepwise because of technical conditions and the increased capacity may therefore be greater or smaller than the excess demand. The syndicate of network owners has to decide if a capacity expansion characterized by an increase in capacity from  $x^K$  to  $x^{K+k}$  should be undertaken.<sup>3</sup>

In Figure 1, we have illustrated an optimal stepwise capacity increase. We have assumed that the sum of network owners' and the third party's demand ( $x_1 + x_2 + x_T$ ) is equal in every period and for period  $n$  could be illustrated by the demand curve  $D$  in the figure. The demand varies with different tariffs,  $\tau$ , the network owners have to pay. The marginal transportation cost,  $\frac{\partial C^t}{\partial x_i}$  is denoted  $mc$  in the figure and is assumed to be constant whenever the short-run capacity limit is not reached. The short-run marginal cost for capacity  $x^K$  and  $x^{K+k}$  is given by  $srmc^K$  and  $srmc^{K+k}$ , respectively. These curves become vertical when the capacity limit is reached. The costs of the capacity expansion per period could be illustrated by the rectangle  $bdfg$  with maximal use of the capacity. The capacity expansion is optimal because the willingness to pay net of transportation costs (net surplus),  $ade$ , is greater

<sup>2</sup>This approach parallels Cremer and Laffont (2002).

<sup>3</sup>We use the superscript  $K$  to denote the existing gas grid, the superscript  $K+k$  to denote the gas grid after the expansion and superscript  $k$  to denote the expansion.



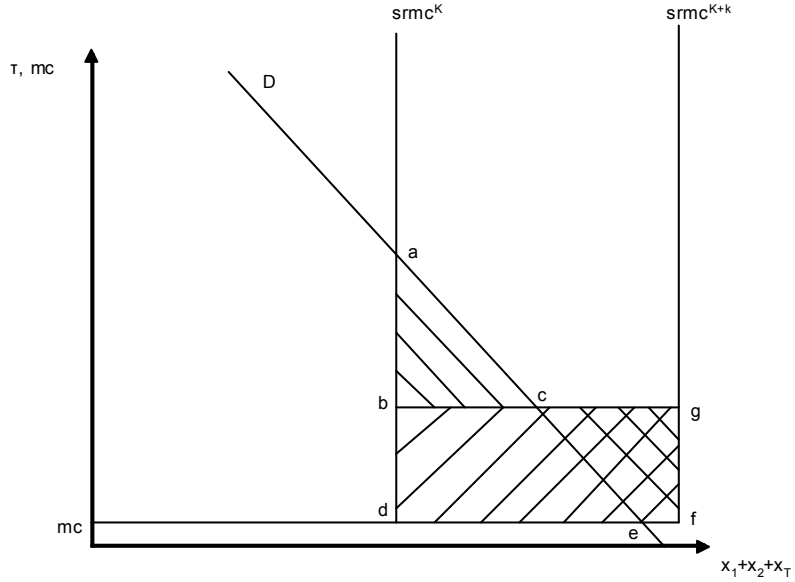


Figure 1: Stepwise capacity increase

than or equal to the periodical capacity costs. However, that requires the optimal short-run price to be equal to marginal cost ( $\tau = mc$ ), and the tariffs would not cover the capacity costs<sup>4</sup>.

On the Norwegian continental shelf it is assumed that most of the transportation costs are investment costs. Therefore, in an uncongested gas grid the optimal tariff in the short run may not cover the investment costs. If the regulator sets the transportation tariff equal to the short-term optimal access prices, this may under full cost coverage reduce the incentives to invest and upgrade the existing gas pipelines considerably as long as the regulation agency does not subsidize the syndicate of network owners. On the other hand, a higher price than marginal cost will not be optimal according to

<sup>4</sup>For a planner it would be optimal to subsidize the syndicate with an amount equal to the consumer surplus and set the tariff equal to marginal cost. However, we assume that for various reasons the regulator is legally prevented from transferring money to the syndicate.

short-run efficiency.

Nonlinear tariffs with perfect information about the network owners' and the third party's preferences, where they pay a fixed fee equal to the sum of their willingness to pay above marginal costs and a variable tariff equal to marginal costs, could eliminate the cost recovery problem. However, the network owners' preferences are normally private information.

In the next sections, we discuss how this information can be elicited through mechanism design. We assume that the costs of providing an investment are common knowledge among the regulator, the network owners and the third party. However, the network owners' willingness to pay for the investment are private information. The mechanism design should induce the network owners to reveal their preferences truthfully so that only an investment that is profitable for the syndicate is undertaken. We assume that the tariff is known to the network owners and the third party before the investment process and that the third party can commit to buy transportation rights at the given tariff before the investment. The third party's willingness to pay for the investment is not revealed through the investment mechanisms. The third party would have incentives to report a greater demand for transportation rights than his actual demand as long as his total willingness to pay is greater than the total tariff payments for his actual demand; i.e., his (inverse) demand curve is downward sloping. This is because of the fact that a reduction in his demand may cancel the whole investment project. Therefore, to some extent the mechanism design takes into account that the third party's willingness to pay for additional capacity could be above the tariff.

If the increased capacity is greater than the excess demand, the transportation capacity may be seen as a public good for the owners. An investment may be comparable to a nonexcludable public good if the syndicate does not exclude any network owner although exclusion could be technically possible<sup>5</sup>. Although expanded capacity in a pipeline may produce externalities, it may be possible to measure the increased transport capacity in the grid. Then an investment could be comparable to an excludable public good. In some cases, the expansion of the gas grid capacity may alternatively be seen as an investment in private means of transportation if the capacity is still congested after the expansion.

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<sup>5</sup>If the investment changes the transport capacity in the entire pipeline system, exclusion may not be technically possible either.

### 3 The transportation capacity as a public good

In this section, we discuss mechanisms that can reveal the network owners' willingness to pay when the transportation capacity is in fact a public good to the network owners. The network owners have to make a joint decision of whether to invest or not. If they invest, the capacity limit would be greater than the demand. An optimal investment mechanism will depend on whether the network owner can be excluded from the capacity expansion or not.<sup>6</sup> We assume that the network owners cannot be excluded from the capacity expansion.

In some cases, it is convenient to write a network owner's willingness to pay for the investment net of cost and regulated income ( $B_i$ ):

$$B_i = \left( \begin{array}{c} p_i x_i - c_i^a(x_i) - \tau x_i + \\ \alpha_i(\tau(x_1 + x_2 + x_T) - C^t(x_1, x_2, x_T) - \alpha_i C^K(x^K)) \end{array} \right) \quad (2)$$

Therefore, network owner  $i$ 's profits are given by:

$$\pi_i = B_i - T_i. \quad (3)$$

A network owner's reported willingness to pay is denoted  $\widehat{B}_i$ , to distinguish it from his true valuation,  $B_i$ . The decision as to whether the investment should be undertaken or not will be a function of the network owners' reported willingness to pay,  $(\widehat{B}_1, \widehat{B}_2)$ . Network owner  $i$  will report his willingness to pay for a capacity expansion to maximize his own profits.

$$\max_{\widehat{B}_i} \pi_i = B_i - T_i(\widehat{B}_1, \widehat{B}_2), \quad (4)$$

where  $T_i(\widehat{B}_1, \widehat{B}_2)$  is the amount network owner  $i$  pays in addition to his share of the investment costs and is dependent on the network owners' reported willingness to pay.

Because of technical specifications of pipelines and compressors, the expansion of the gas grid has to be made stepwise. The syndicate of network owners has to decide if a capacity expansion characterized by an increase in capacity from  $x^K$  to  $x^{K+k}$  should be undertaken or not.

A member's total profit from a capacity increase  $x^k$  is then given by:

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<sup>6</sup>The possibility of exclusion could alter the preferable investment mechanism.

$$\pi_i^k = B_i^{K+k} - B_i^K - T_i(\widehat{B}_1^{K+k} - \widehat{B}_1^K, \widehat{B}_1^{K+k} - \widehat{B}_1^K). \quad (5)$$

This could alternatively be written as:

$$\pi_i^k = B_i^k - T_i(\widehat{B}_1^k, \widehat{B}_2^k) \quad (6)$$

If the investment is not implemented, the change in profit is given by:

$$\pi_i^k = -T_i(\widehat{B}_1^k, \widehat{B}_2^k). \quad (7)$$

### 3.1 Investment payments equal to reported willingness to pay

The government may design an investment mechanism where the investment is undertaken if  $\widehat{B}_1^k + \widehat{B}_2^k \geq 0$ . If network owner 1 has reported  $\widehat{B}_1^k < 0$  he might be compensated by the other if  $\widehat{B}_2^k \geq 0$ . Therefore, the investment costs are divided among the network owners according to their reported willingness to pay and their shares in the syndicate. The total monetary investment costs for owner  $i$  is equal to:

$$\left( \alpha_i C^k(x^k) + \widehat{B}_i^k \right) \left( \frac{C^k(x^k)}{C^k(x^k) + \widehat{B}_1^k + \widehat{B}_2^k} \right), \quad (8)$$

where  $C^k(x^k) = C^{K+k}(x^{K+k}) - C^K(x^K)$ . The first part is his total reported willingness to pay for the investment to be undertaken and the second part downscales the total reported willingness to pay to the investment costs.

The members in the syndicate have to decide whether they should invest or not. If a member knows that he has to pay at least  $B_i^k$ , to ensure the investment occurs, his reported willingness to pay will be equal to  $B_i^k$ . He will not pay more than  $B_i^k$ . However, if he believes that the syndicate will invest regardless of what he pays for the investment, he might be tempted to free ride on the other member. In general, member  $i$  does not know for sure whether he can free ride on the other or not. Nevertheless, his reported willingness to pay might be lower than  $B_i^k$  because there is a positive probability that the capacity increase will be undertaken anyway. Then the reported total willingness to pay for the two members may be lower than  $B_1^k + B_2^k$ , and the capacity investment may not take place even though it is profitable for the syndicate as a whole.

## 3.2 The Vickrey–Clarke mechanism

The incentive problem in this setting has much in common with the incentive problem in a sealed-bid auction for a private good. Vickrey (1961) discussed an auction mechanism in which the bidders' true willingness to pay for a private good is revealed. Each member of the group makes a sealed bid under the condition that he only has to pay the second highest bid price. The member with the highest bid pays a price equal to the value for the member with the second highest bid, which is the relevant opportunity cost. This auction mechanism is called the second-price auction. Clarke (1971) developed this auction mechanism further so as to reveal the willingness to pay for a public good. This mechanism is called the pivotal mechanism or the Vickrey–Clarke mechanism as it is a variety of a Vickrey auction.<sup>7</sup> The winner of the Vickrey auction is always pivotal because he gets the commodity instead of the one whose bid came second. The maximum utility loss for the members, except the winner, is the second highest bid, because the others are completely unaffected. With the Vickrey–Clarke mechanism the pivotal member pays the maximum cost imposed on other members because the allocation is being changed. Therefore, the second-price auction is the natural private goods counterpart to the Vickrey–Clarke mechanism for public goods.

This mechanism is called the pivotal mechanism because an amount of money is paid by member  $i$  only in the case his reported willingness to pay  $\widehat{B}_i^k$  is pivotal for the investment decision. Pivotal means that the member's reported willingness to pay changes the investment decision of the syndicate. Truthful revelation is critical for a correct investment decision. The general rule is that member  $i$  should face a price reflecting the cost his report is imposing on the other member. The reason for this is that the pivotal member changes the investment decision and his payment should capture the externality his decision is imposing on the other owner. This externality could be of two types. First, network owner  $i$ 's reported willingness to pay for the project is negative and changes the investment decision so that a project that is profitable for the other network owner is not undertaken. Second, a project that is not profitable for the other network owner is realized because of network owner  $i$ 's reported willingness to pay.

The Vickrey–Clarke mechanism is a solution to the free rider problem

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<sup>7</sup>Joskow and Tirole (2004) discussed the use of the Vickrey–Clarke mechanism as a mechanism to induce optimal investment in reliability of an electricity network. Such an investment could be seen as an investment in a public good.

above because of the fact that an agent internalizes the externality that his decision is imposing on the other agent. The Vickrey–Clarke mechanism is a direct revelation mechanism where truth-telling is a dominant strategy and for which the investment is made if and only if  $B_1^k + B_2^k \geq 0$ . Network owner  $i$ 's reported willingness to pay changes the investment decision only if  $B_i^k + B_j^k$  and  $B_j^k$  have opposite signs.<sup>8</sup> If network owner  $i$  is pivotal and changes the investment decision, the other member suffers a loss equal to the absolute value of his reported willingness to pay. This loss might be a loss of profits or increased costs depending on how network owner  $i$ 's reported willingness to pay changes the investment decision. If network owner  $i$  is pivotal, his profits are equal to:

$$\pi_i = B_i^k - \left| \widehat{B}_j^k \right|, \quad (9)$$

where  $\left| \widehat{B}_j^k \right|$  is the absolute value of  $\widehat{B}_j^k$ , if the investment is undertaken and  $\pi_i = -\left| \widehat{B}_j^k \right|$  if the investment is not implemented.

The Vickrey–Clarke mechanism is a variety of Vickrey's sealed bid second-price auction, where  $\left| \widehat{B}_j^k \right|$  is the highest bid network owner  $i$  has to match to change the investment decision. Therefore, a higher bid can be compared to winning the second-price auction. Network owner  $i$  changes the investment decision if  $\widehat{B}_i^k$  is positive and larger than  $\left| \widehat{B}_j^k \right|$  when  $\widehat{B}_j^k < 0$  or if  $\widehat{B}_i^k$  is negative and larger than  $\left| \widehat{B}_j^k \right|$  when  $\widehat{B}_j^k > 0$ .

We assume that  $\widehat{B}_j^k \geq 0$  such that network owner  $j$  has reported a positive willingness to pay for the project. If the total willingness to pay is also positive; i.e.,  $B_i^k + \widehat{B}_j^k \geq 0$ , network owner  $i$  has incentives to report truthfully regardless of whether he has a positive or negative willingness to pay. The reason for this is that he would not increase his profit by reporting a higher willingness to pay than his true one, and if  $B_i^k < 0$ , reporting a lower willingness to pay might cancel the project and network owner  $i$  has to pay  $\widehat{B}_j^k$ . By assumption this is larger than the loss  $\left| B_i^k \right|$ , which he has to pay if he reports the true value. Therefore, network owner  $i$  has an incentive to report truthfully if  $\widehat{B}_j^k > 0$  and  $B_i^k + \widehat{B}_j^k \geq 0$ . The same reasoning applies if  $\widehat{B}_j^k > 0$  and  $B_i^k + \widehat{B}_j^k < 0$ . If the network owner reports the true willingness to pay he has to pay  $\widehat{B}_j^k$ , and his loss will also be  $\widehat{B}_j^k$  if he reports a lower

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<sup>8</sup>The pivotal mechanism can easily be generalized to more than two network owners.

value. If he reports a higher value, the project might be realized and he will have a loss of  $B_i^k$ , which by assumption is larger than  $\widehat{B}_j^k$ . Similar results could be shown for the case  $\widehat{B}_j^k < 0$ .

Therefore, truth-telling is a dominant strategy for network owner  $i$  and symmetrically for network owner  $j$ . Because of this fact the Vickrey–Clarke mechanism ensures that only projects that are profitable for the syndicate as a whole will be undertaken. Strategic bids are not profitable because a pivotal network owner (winner of the auction) does not pay his own bid. In the Vickrey–Clarke mechanism, the second highest bid is equal to the total net willingness to pay for the members of the syndicate except for the pivotal member.

To illustrate the Vickrey–Clarke mechanism we use a numerical example. We assume that the investment project gives an capacity increase of 10 units with an investment cost of 1000 per period; i.e.,  $C^k(x^k) = 1000$ . The capacity is uncongested after the expansion, and the transportation capacity may then be seen as a public good. Assume that their willingness to pay for increased capacity, exclusive of their share of the investment costs, are 575 and 475 for network owner 1 and network owner 2, respectively. Because the total willingness to pay is 1050, which is greater than the investment cost, the project is profitable for the syndicate. Assume that each network owner owns 50% of the syndicate, and that they have to pay half of the investment cost each. Therefore, network owner 1’s net willingness to pay,  $B_1^k$ , is 75, while network owner 2’s net willingness to pay,  $B_2^k$ , is -25. Network owner 1 has to pay 25 in information costs, because of the fact that he changes the investment decision from not invest to invest. The total payments of network owner 1 and network owner 2 are 525 and 500, respectively. Although network owner 2 is willing to pay only 475, he still has to pay 500 for the investment project.

The Vickrey–Clarke mechanism ensures truthful reports of willingness to pay for investment in a public good. In this case, the public good is transport capacity in a gas grid. However, the Vickrey–Clarke mechanism as an incentive device for investment decisions raises certain problems. First, to ensure truthfully reported willingness to pay, the network owners have to pay an extra cost in addition to the investment costs. After the investment costs are distributed among the network owners, the mechanism generates a surplus as long as there exists one or more pivotal members. This surplus cannot be returned to the members or be used for a later project. There-

fore, the surplus has to be destroyed or used for other purposes that do not benefit the members. Otherwise it would affect the incentives for truthful reporting. Consequently the Vickrey–Clarke mechanism does not lead to a balanced budget. The surplus may however be seen as an extra cost of having the network owners’ true preferences revealed voluntarily. Information costs also appear for other incentive mechanisms for revealing agents preferences; i.e., screening mechanism for consumers willingness to pay in markets for private goods. In such cases the information costs appear in the market as an efficiency loss because of self-selection of the buyers, according to their willingness to pay. Therefore, the information costs become less visible compared to the Vickrey–Clarke mechanism, where the mechanism generates a cash surplus that has to be used for other purposes that do not benefit the members.

So far, we have not considered any relations between the pipeline owners and the government. However, if we assume that the syndicate is subject to taxation, the government can confiscate the payments  $T_i(\widehat{B}_1^k + \widehat{B}_2^k)$  from member  $i$  as a tax. This tax will not affect the optimal solution. It will be in the nature of a lump-sum tax triggered by the pivotal decisions. If the information costs take the form of a lump-sum tax, there will not be any welfare loss because of revelation of the network owners’ preferences.

Second, the mechanism may not satisfy the conditions for voluntary participation<sup>9</sup>. Even though the investment is not made, one of the members of the syndicate may end up paying a tax. If the investment is undertaken, a network owner may have to pay a larger amount of money than his willingness to pay because he has to pay an ex ante given part of the investment costs. Therefore, ceteris paribus, a network owner might ex post have been better off by not participating in the capacity expansion. However, because of possibly large overall benefits from participating in the syndicate, this may be a minor problem.

Third, the Vickrey–Clarke mechanism can be open to coalitional manipulation. The Vickrey–Clarke mechanism used in this paper can easily be generalized to arbitrarily many network owners,  $I$ . In that setting, two or more of the members may cooperate in a coalition. For example, if two gas producers both report that their periodical willingness to pay for the project is  $C^k(x^k)$ , the investment will be made and the gas producers pay

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<sup>9</sup>Voluntary participation constraint says that everyone should benefit, or at least no one suffer, compared to the situation where no public good is produced, Moulin (1994).



only their own share,  $\alpha_i$ , of the investment costs and no one pays tax to the government. In addition, the gas producers are ensured a regulated income  $\alpha_i(\tau \sum_{i=1}^I x_i^k - C^t(\sum_{i=1}^I x_i^k))$  from the use of the increased capacity if we assume there are  $I$  gas producers. On the other hand they have to pay  $\tau x_i^k$  for the use of the grid. Even though the two gas producers may be the only ones that benefit from the capacity expansion, their costs in connection with the investment may be relatively small. The problem of coalitional manipulation may be reduced by monitoring whether the network owners' reported willingness to pay is reasonable relative to their use of the capacity expansion. If the syndicate structure is meant to last for many years, the network owners will have weaker incentives to manipulate so as to not reduce the future benefits from cooperating.

### 3.2.1 Regulatory policy and the Vickrey–Clarke mechanism

So far, we have not discussed regulatory policy. We assume that the regulator can choose between two regulatory regimes. The first regime sets the tariff rates equal to an estimate of marginal transportation costs,  $\tau = \frac{\partial C^t}{\partial x_i}$ , while the second one is set so that the regulatory income net of transportation costs is estimated to cover the capacity costs,  $\tau(x_1^k + x_2^k + x_T^k) - C^t = C^k(x^k)$ . As long as the regulatory tariffs are set prior to the investment decision, both regimes would satisfy the conditions for a regulatory regime in the analysis above.

The problems of the Vickrey–Clarke mechanism as a device for investment decisions are related to the choice of regulatory policy. If the tariff rates are set equal to marginal costs, the tariff rates combined with the Vickrey–Clarke mechanism and investment costs may be seen as a two part tariff, where the network owners pay  $\alpha_i C^k(x^k) + T_i$  as a fixed cost for the option to use the capacity expansion and a variable cost  $\frac{\partial C^t}{\partial x_i}$  for transportation of gas. This mechanism will satisfy both short-term and long-term efficiency. However, as discussed above, the mechanism is open to coalitional manipulation and may not satisfy the conditions for voluntary participation. The principles in the EU directive of open access on nondiscriminatory conditions may also undermine the investment decision. If the competitors to the network owners only have to pay marginal costs for transportation, the advantage of participating in the syndicate might be reduced.

The alternative regulation policy, where the tariff rate is also estimated to cover the capacity costs, would not be optimal in the short run with unused capacity because the tariff is set above marginal costs. Because the part of the tariff exceeding marginal costs is paid to the other owners,  $\left(\tau - \frac{\partial C^t}{\partial x_i}\right)(1 - \alpha_i)$ , this will not only affect the short-run efficiency but also the investment incentives. In their reported willingness to pay, the network owners will take into account that they will demand fewer capacity units compared with a situation where they pay a tariff equal to marginal costs for transporting gas. However, such tariffs will reduce the problems caused by the Vickrey–Clarke mechanism because the payment from the users of the transportation capacity would cover the investment costs. Therefore, the problems of voluntary participation and coalition manipulation and the influence from open access and nondiscriminatory tariffs on the investment decision may be less serious.

However, if the higher tariffs should reduce the problems according to the Vickrey–Clarke mechanism, it is important that the users of the increased capacity have to pay a larger part of the investment costs. If the investment is financed through general tariffs from use of the overall gas grid, the payments from the shippers for the capacity increase do not have to reflect the investment cost. This may be because of the fact that the use of the increased capacity is low or that the costs of new capacity are much larger than the costs of existing capacity. Then it may be possible to shift some of the investment costs from the shippers to the owners of the network. However, this is not a problem according to the Vickrey–Clarke mechanism, but a general problem for several mechanisms, which may cause overinvestment in the grid.

## 4 Network owners can be excluded from the capacity expansion

In some cases, the expansion of the capacity of the gas grid may alternatively be seen as an investment in a good where exclusion is possible. This could be the case where the expansion is a pipeline to a new market. However, this may even be the case if the capacity increase comes from investment in a new compressor. In the latter case, it could be possible to exclude some of the members of the syndicate from using the increased capacity even if

the investment produces externalities for the rest of the gas grid. If the investments make it possible to exclude members of the syndicate from using the capacity increase and the capacity increase is so large that it renders the users nonrivalrous, it is possible to design a mechanism with exclusion. Then, the investment has the characteristics of an impure public good and is defined as a good for which consumption is nonrivalrous but where exclusion is feasible.

The possibility of exclusion allows one to apply an auction-like mechanism (ALM) for allocating the public good. Our point of departure is an English auction-like mechanism (EALM) proposed by Deb and Razzolini (1999). This is a rising-price auction-like mechanism, which resembles the English auction for a private good.

Let  $x^k$  be the capacity limit of the expansion. In this section, we assume that the members of the syndicate and the third party have an increase in demand for capacity units, which never exceeds the capacity limit,  $x^k \geq x_1^k + x_2^k + x_T^k$ . Therefore, we rule out rivalrous demand. Capacity is a common factor of production.

In an English auction for a private good, the price is raised until only one bidder remains. The auctioneer starts with the reservation price and calls out successively higher prices until only one bidder remains active. The reservation price represents the value or cost of the good to the auctioneer. The good is sold to the highest bidder at the bid price. For each bidder, the dominant strategy is to remain active as long as his valuation of the good is not lower than the price. In an open auction where the bids are raised successively, the winning bid is only marginally greater than the second highest bid. Therefore, this auction gives approximately the same outcome as Vickrey's "second best auction".

In Deb and Razzolini (1999), the English auction for a private good is modified to an EALM. Because a public good is involved, the objective of the auctioneer is different. They assume that the auctioneer wishes to maximize the welfare of the potential buyers rather than the sales price. In our settings, this means that the auctioneer wishes to maximize the profits of the members of the syndicate<sup>10</sup>. This entails that access to the increased capacity is sold at the lowest possible, but equal, price to the individual members. The EALM also differs from an English auction for a private good because unlike private

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<sup>10</sup>The results may differ if we assume that domestic taxation is generally distorting so that there is a premium on public revenue.

goods, the same good can be sold to several individuals simultaneously. In the case of a public good, the reservation price is the social opportunity cost of producing the good. With respect to the capacity expansion, the opportunity cost will equal the investment cost,  $C^k(x^k)$ . The reservation condition would then be  $jp \geq C^k(x^k)$ , where  $j$  is the number of members of the syndicate who will demand a gas transportation right at the sales price  $p$ . In standard auction theory, it is assumed that the good has already been produced. Here the question is whether the investment in capacity expansion should be undertaken or not.

In our version of the EALM, the auctioneer starts out with the price of  $C^k(x^k)/I$  and calls out successively higher prices, until a sufficient number of members will pay the given bid price for the reservation condition to be met. The auctioneer stops calling higher prices when either the investment amount is reached or when the price reaches a level where no members will participate in the capacity expansion. If the reservation condition is met at  $C^k(x^k)/j$ , the  $j$  members of the syndicate may use the expanded capacity for  $n$  periods and pay the price  $p$ . The other members,  $I - j$ , are excluded. If the reservation condition is not met, the investment in capacity expansion is not undertaken. This mechanism is not only strategy proof, but also coalitionally nonmanipulable, see Deb and Razzolini (1999) and Moulin (1994). As Deb and Razzolini pointed out, the welfare loss from the EALM will take the form of a utility loss from excluding some individuals from consuming the public good. In the case of uncongested capacity expansion, the members of the syndicate would not be charged more than the investment cost.

We can use the same numerical example as for the Vickrey–Clarke mechanism to illustrate the EALM. The investment cost is equal to 1000 per period, the network owners willingness to pay for increased capacity are 575 and 475 for network owner 1 and network owner 2, respectively. Following the EALM the auctioneer starts out with the price  $1000/2=500$ . Because owner 2 has a lower willingness to pay, he will be excluded. The auctioneer calls out successively higher prices until the price exceeds 575, where no members will participate in the capacity expansion. Therefore, the investment will not be undertaken although the total willingness to pay is greater than the investment costs.

Each member of the syndicate may have a different willingness to pay for the investment because some of them may have large while others have small transportation needs. Using the EALM, every member pays the same price to access the capacity expansion independent of their demand for gas trans-

portation. Therefore, the EALM does not ensure that the investment takes place even though the total willingness to pay for the investment exceeds the costs. One way to modify this problem may be to let  $j$  be the number of capacity units demanded instead of the number of members. Then the auctioneer starts with the price  $C^k(x^k)/x^k$  and calls out successively higher prices, until the demand for capacity units is sufficiently high for the given bid price for the reserve condition to be met. The auctioneer stops calling higher prices when either the investment amount is reached or when the price reaches a level where nobody demands capacity units. If this mechanism should be similar to the EALM in Deb and Razzolini (1999), the excess capacity has to be unused or sold at a price at least equal to the auction price. Otherwise, the network owners have incentives to underreport their transportation needs and free ride on the others. The mechanism could be a form of partial exclusion, discussed in Moulin (1994), where the members will be excluded from using transportation capacity above their reported demand.

Using the EALM with capacity units, a network owner's willingness to pay for an extra capacity unit may be larger than his marginal willingness to pay, because of the fact that a reduction in his demand may cancel the whole investment project. A network owner would have incentive to report willingness to pay somewhere between his marginal willingness and his average willingness to pay for the capacity units he demands. Therefore, to some extent the mechanism takes account of the fact that a gas producer has different willingness to pay for each capacity unit. If a gas producer's average willingness to pay for the capacity units is 100, while his marginal willingness to pay is 50, he has incentives to bid more than 50 for the marginal unit. If the auction price exceeds 50, the gas producer knows that there is a positive probability for the investment not to be undertaken if he reduces his demand price for the marginal unit. He will, therefore, bid more than 50 for the marginal unit to increase the probability for the investment to be undertaken.

Because the network owners all pay the same price for reserved capacity units, the mechanism will not be open for coalitional manipulation. The EALM leads to a balanced budget and satisfies the condition of voluntary participation. Because of the stepwise nature of the investment the capacity expansion may give rise to excess capacity. In the Vickrey–Clarke mechanism, it is important that the members do not attain any benefits from the extra surplus. In the first version of EALM, it is important that the excluded members do not have access to excess capacity. In the EALM with a unit

price of transportation, it is important that no one has access to excess capacity at a lower price than they have to pay according to the mechanism. If they could buy this excess capacity at a lower price later on, their incentives to report their true willingness to pay for gas transport may be diluted. When the capacity expansion has been made, it would be optimal ex post to sell the excess capacity at a price equal to short-run marginal cost.<sup>11</sup> This transaction could take place between the members of the syndicate in the second-hand market or between an independent system operator and eligible customers<sup>12</sup>. To ensure efficient incentives for investment, it is important that the excluded and partly excluded members remain so in the second-hand market. Alternatively, the regulatory authority has to introduce minimum prices in the second-hand market and for excess capacity sold by the independent system operator. Before implementing these restrictions one has to be aware of the fact that the optimal short-run access price would be altered.<sup>13</sup>

By using the EALM to allocate capacity, this mechanism could be combined with a regulated tariff set equal to marginal costs,  $\tau = \frac{\partial C^t}{\partial x_i}$ . When the investment is undertaken, the network owners will choose optimal short-run quantities if they are not excluded or partly excluded by the EALM. However, as mentioned above, there has to be restrictions in the second-hand market and on the sale of excess capacity. The welfare loss of this mechanism is due to being (partial) excluded. There may also be some problems associated with the principles in the EU directive of open access on nondiscriminatory conditions with respect to the restriction in the second-hand market and on the sale of excess capacity. Compared with the Vickrey–Clarke mechanism there will also be a welfare loss in the investment decision. In the EALM, every network owner pays an equal price, both in the general EALM and the EALM with a unit price of transportation. The EALMs will not take into account the differences in willingness to pay for access to the network or for the capacity units. This is because of the fact that the investments have to be stepwise. If the network could be expanded by one capacity unit, this unit could be sold as a private good to the highest bidder. However, the Vickrey–Clarke mechanism will manage to take into account differences in

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<sup>11</sup>The incentive problems associated with selling excess capacity at a lower price after the auction is closed, is analogous to the time inconsistency problem in Coase’s “durable goods monopoly”, see Coase (1972).

<sup>12</sup>The governing principle in the EU directive also suggests that access should be given to natural gas undertakings and eligible customers.

<sup>13</sup>There may also be restrictions in the EU directive against such a policy.

willingness to pay and price discrimination among the network owners.

The alternative regulation policy, where the tariff rates also cover the capacity costs, would not be optimal in the short run with unused capacity because the tariff is set above marginal costs and the part of the tariff exceeding marginal costs is paid to the other owners. This is equivalent to the short-run situation for the Vickrey–Clarke mechanism. This will not only affect short-run efficiency but also the investment incentives. In their auction bid, the network owners will take into account that they will demand fewer capacity units compared with a situation where they pay a tariff equal to the marginal costs of transporting gas. However, with higher tariffs the influence of open access and nondiscriminatory tariffs on the investment decision may be less serious.

## 5 Congested capacity expansion

In this section, we relax the assumption that the capacity expansion is uncongested. Because the investment is stepwise, it may not necessarily be profitable to eliminate the scarce capacity in the gas grid. This may be because of the fact that the excess demand for transportation capacity is not large enough to make the next step of capacity increase profitable for the syndicate. In that case, the prices play a dual role. They function both as a revelation mechanism and as a rationing device to allocate a scarce good. Therefore, the members of the syndicate have an excess demand for capacity, which exceeds the capacity limit for the new investment,  $x_1^k + x_2^k > x^k$ . The capacity has to be rationed among the network owners. However, if the excess demand, inclusive of the demand of the third party, exceeds the capacity limit, while the excess demand of the network owners does not; i.e.,  $x_1^k + x_2^k + x_T^k > x^k$  and  $x_1^k + x_2^k < x^k$ , the capacity may be rationed by the rule that the network owners have priority as in the Norwegian grid.

Because the capacity is also congested after the expansion, the transportation capacity has the characteristics of a private good. In allocating capacity units among the network owners, an auction like method may be preferable to a pro rata sharing of the costs of the investment. Using the framework of Deb and Razzolini (1999), the auctioneer starts with the price  $C^k(x^k)/x^k$  for rights to transport gas through the gas grid for a given period, raising the price until  $x^k$  capacity units are demanded. This is the lowest

price that covers the investment costs and ensures that no more than  $x^k$  capacity units are demanded. However, our setting differs from theirs. In their model, the good is a public good, and there is a maximum number of individuals who may use it. Then the mechanism in Deb and Razzolini would give an effective allocation as long as the surplus revenue generated by the auction is destroyed. In our setting, a member of the syndicate may demand more than one unit of the capacity expansion. Then this member has to take into account that the demand for an extra unit may increase the price he has to pay for the other units. Therefore, the members' incentives to report their true willingness to pay for gas transportation may be distorted.

To ensure an optimal allocation of the transportation capacity, we need an auction mechanism that gives the network owners incentives to report their true willingness to pay for the investment project. Vickrey (1961) generalized the second-price auction mechanism to an auction mechanism where the bidders can bid on several units. Ausubel (2004) further developed Vickrey's solution to the multi-unit problem. Ausubel showed that the solution is to allocate the units to the bidders according to the opportunity cost principle, where the winners of the capacity units pay the opportunity cost to the other bidders following the principle of a second-price auction for a single private good. Vickrey demonstrated this principle for multiple sales. A bidder  $i$  is characterized with a demand curve  $x_i(p)$ , and every bidder bids by reporting his demand curve to the auctioneer. The total quantity is given by  $M$ , and we let  $M - x_{-i}(p)$  be the residual quantity to bidder  $i$  after the others' demands,  $x_{-i}(p)$ , are subtracted from the total quantity. We let  $p^*$  be the market price when all bidders participate in the auction, and  $p_{-i}^*$  be the market price when all the bidders except bidder  $i$  bid in the auction. According to the second-price principle, bidder  $i$  wins  $x_i(p^*)$  units and pays the area under the inverse supply function  $M - x_{-i}(p)$  over the interval from zero to  $x_i(p^*)$ . This is illustrated in Figure 2.

The area under the net supply curve faced by bidder  $i$  is equal to the opportunity cost for the other bidders if bidder  $i$  gets the quantity  $x_i(p^*)$ . Hence, the allocation is efficient. We also see that the price bidder  $i$  has to pay is independent of his marginal willingness to pay for an extra unit of the good. This ensures that the bidders have incentives to report their true marginal willingness to pay and their true demand curve.

Ausubel (2004) discussed an efficient ascending-bid auction for multiple objects. This is a discrete version of Vickrey's second-price auction for multiple sales. In our setting, the auctioneer starts with the price  $p_0 = C^k(x^k)/x^k$ ,



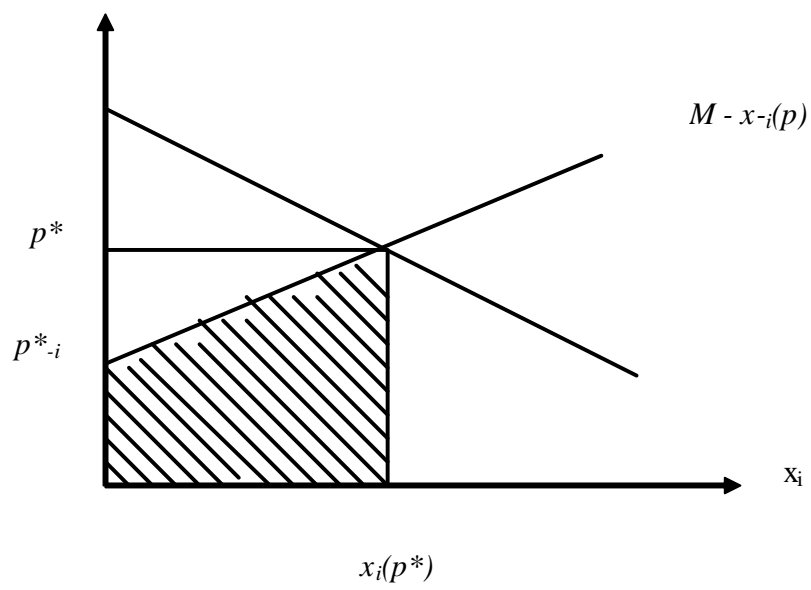


Figure 2: Second price auction for multiple sales

	Network owner 1 (50%)	Network owner 2 (50%)
1. unit	150	160
2. unit	140	135
3. unit	130	100
4. unit	120	80

Figure 3: Willingnesses to pay for increased capacity

raising the price until  $x^k$  capacity units are demanded. To explain how the units are allocated, we look at the auction from bidder  $i$ 's perspective. If the demand from all the bidders other than bidder  $i$  at the price  $p_1 > p_0$  is  $x^k - 1$ , bidder  $i$  is winning one unit at the price  $p_1$ . The price  $p_1$  is the highest price the group of other members would pay. Hence, this is the opportunity cost of allocating the first unit to  $i$ . The auction proceeds by raising the price from  $p_1$ . If the demand from all the bidders other than bidder  $i$  at the price  $p_2 > p_1$  is  $x^k - 2$ , then bidder  $i$  is winning one additional unit at the price  $p_2$ . This auction process goes on looking at the situation from all the bidders perspective until  $x^k$  capacity units have been allocated. This auction yields the same outcome as the sealed-bid multi-unit Vickrey auction, see Vickrey (1961), as long as the bidders do not increase their demand for capacity units as the price is raised. As before, the amount of money collected in excess of the investment costs is paid as a tax to the government from which the members must not benefit.

To illustrate this mechanism, we can use a numerical example. We assume that the investment project gives a capacity increase of 4 units with an investment cost of 500 per period; i.e.,  $C^k(x^k) = 500$ . The network owners' net willingness to pay for increased capacity are given in Figure 3. Capacity is also scarce after the expansion, and if it is possible to exclude the network owners from using the capacity, the transportation capacity is a private good. The reservation price,  $p_0 = 500/4 = 125$ . The demands of the network owners are given in Figure 3.

The demand of network owner 1 is given by  $x_1(125) = 3$  and network owner 2's demand is given by  $x_2(125) = 2$ . The total quantity is equal to 4

and at the price  $p_0 = 125$ ,  $M - x_2(125) = 2$  and  $M - x_1(125) = 1$ . Therefore, network owner 1 wins two units, and network owner 2 wins one unit at the price 125. Increasing the price to  $p_1 = 130$ , network owner 1 reduces his demand to two units, while network owner 2's demand is unchanged. Therefore,  $M - x_2(130) = 2$  and  $M - x_1(130) = 2$ , and network owner 2 wins one additional unit at the price  $p_1 = 130$ , which is the opportunity cost to network owner 1 for this unit. Hence, the 4 units are allocated among the network owners with 2 units to each. The total payments are 505, which are five above the investment costs. This amount is paid as a tax to the government from which the members must not benefit.

This auction is incentive compatible in the sense that the members have nothing to gain by underreporting their willingness to pay. However, the auction mechanism is coalitionally manipulable because of the fact that the members may agree to reduce their demands so that the unit prices are reduced. The cooperation among the members will only reduce the extra amount of money paid in taxes, it would however not change the decision to expand the capacity or not. The members of the syndicate have incentives to report their demands truthfully for the price  $p = p_0$ . Otherwise, the investment might not be implemented although the network owners have high enough willingness to pay for the project, and all the members will suffer a loss. However, for a higher price the network owners have to pay the price difference  $p_1 - p_0$  as a tax. Therefore, they could make agreements and ration the transportation capacity among them without using the auction price as a rationing device.

For the case with congested capacity expansion, an Ausubel auction to allocate capacity combined with a tariff equal to marginal costs will satisfy both short-term and long-term efficiency. Because the capacity in this case is scarce, there is no need for any restrictions in the second-hand market. A higher tariff than marginal costs will reduce the willingness to pay for capacity units and will favor network owners with large owner shares because of the fact that they pay a fraction,  $\alpha_i$ , of the tariff above marginal costs to themselves.

## 6 Conclusion and discussion

In this paper, we have discussed the possibility of designing a mechanism for optimal natural gas pipeline investment, where the transportation system is organized by an independent system operator and the gas grid is owned by a syndicate of gas producers. Asymmetric information about the willingness to pay for a capacity expansion may cause information costs. The information costs arise through the process of preference revelation. We discuss how different mechanisms for revealing the network owners' preferences in interaction with regulatory regimes affect both short term and long-term efficiency.

Because of the technical specifications of pipelines and compressors, the expansion of the gas grid has to be stepwise and may cause both congested and uncongested capacity expansions. We show that investment mechanisms based on the principle of Vickrey's second-price auction combined with regulated tariffs equal to marginal costs would be preferable both when the capacity expansion takes the form of a public good and the gas grid may still be congested after an expansion.

If the capacity expansion takes the form of a nonexcludable public good, using the Vickrey–Clarke mechanism as a device for investment decisions may cause some problems because the mechanism does not satisfy the conditions for voluntary participation and no-coalitional manipulations. If the increased capacity has the characteristics of an excludable public good without congestion, it may be possible to design mechanisms solving the free rider problem associated with collective investments. However, these mechanisms often have drawbacks in that some agents with gas transportation needs may be excluded. It is also important that the members cannot buy excess capacity at a lower price in the second-hand market because their incentives to report the true willingness to pay for gas transport would then be diluted. Compared with the Vickrey–Clarke mechanism the mechanisms with exclusions will also lead to a welfare loss in the investment decision. The auction like mechanisms will not take into account the different willingness to pay among the network owners. The Vickrey–Clarke mechanism will manage to take into account these differences in willingness to pay through price discrimination among the network owners.

A mechanism allocating capacity combined with regulated tariffs equal to marginal costs appears to be preferable because this will satisfy both short

term and long-term efficiency. However, setting higher tariffs may reduce the problems of coalitional manipulation, voluntary participation and open access and nondiscriminatory prices. Higher tariffs may however also alter the short-run and long-run efficiency.

Although the expansion of the gas grid is undertaken stepwise because of technical specifications, the gas grid may still be congested after an expansion. In that case, the capacity expansion may be seen as a multi-object auction sharing the capacity units between the members in an optimal way. Underinvestment, because of free riding and strategic considerations, may favor a congested relative to a noncongested capacity expansion and may cause the expansion to be too small compared with the first best optimal solution.

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