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## The Global Natural Gas Market. Will transport cost reductions lead to lower prices?

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*Knut Einar Rosendahl and Eirik Lund Sagen*

**The Global Natural Gas Market**  
**Will transport cost reductions lead to lower prices?**

**Abstract:**

Reduced transportation costs are usually associated with lower import prices, increased trade and price convergence. In this paper we show that the lower costs can actually lead to higher import prices in some regions, and price divergence between import regions. Using both a general theoretical approach and a numerical model of the global natural gas market, we demonstrate that the price effect from transport cost reductions depend on the relative distances between regional markets, the choice of transport technology, and supply and demand responsiveness in the different markets. Our numerical results suggest that European consumers would generally be better off if pipeline costs are reduced, while North American consumers would be better off if LNG costs are reduced.

**Keywords:** Natural gas, trade, transport costs, price convergence, numerical model

**JEL classification:** C61, F17, L95, Q31, R40

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# 1. Introduction

Natural gas has traditionally been traded in regional markets, like the European, the North American, and the Asia-Pacific markets. Most of the gas to and within Europe as well as North America has been transported in pipelines, whereas the Asia-Pacific market has been dominated by LNG transport. Over the last decade the costs of LNG have been significantly reduced, more producers have entered the gas market in general and the LNG market in particular, and the trade between continents has increased (EIA, 2003; IEA 2006, 2007). IEA (2007) states that LNG accounts for 70% of the growth in inter-regional trade since 2004, and LNG trade volumes are expected to more than double before 2015. This trend reflects the fact that gas resources to a larger extent are located far from the main consuming regions. For instance, whereas the ratio of reserves over annual consumption is 10 years in North America (the largest single gas market), the ratio is almost 300 years in the Middle East (BP, 2007). Moreover, energy-consuming countries are concerned about security of supply, and therefore prefer to import gas from a variety of sources, stimulating both intra- and inter-regional trade.

The reduction of transport costs over the last 10-15 years, especially for LNG, is clearly one of the important driving forces for the growing globalisation of natural gas markets. Brito and Hartley (2007) argue that this change in market structure promoted by transport cost reductions (and other factors) can be significantly accelerated by endogenous expectations about how the market evolves. The LNG chain consists of three separate cost components (besides extraction). The most expensive one (except at very long distances) is liquefaction costs, which decreased substantially during the 1990's and early 2000's (EIA, 2004) and increased again after 2003. According to Grecker and Sagen (2004), the cost reduction may be more due to increased competition among liquefaction technology suppliers than to technological progress. On the other hand, Jensen (2003) emphasizes economies of scale from larger liquefaction trains, and he expects unit costs to fall further in coming years. This is also stated in Jensen Associates (2007), where the substantial increase in LNG plant construction costs since 2003 is treated as "aberrations resulting from a heavily overheated construction industry". The unit costs of LNG shipping have also been reduced significantly, primarily due to larger average cargo volumes and reduced costs of input factors in the construction of LNG ships (EIA, 2003, 2004; Sagen, 2007). The LNG tanker fleet increased by 75 per cent from 2000 to 2005 (IEA, 2006). Pipeline costs have also fallen over the last couple of decades, although not as much as LNG (see e.g. Zhao, 2000). According to EIA (2003), offshore pipeline transport is still the cheapest alternative for distances below 2,000 kilometres.

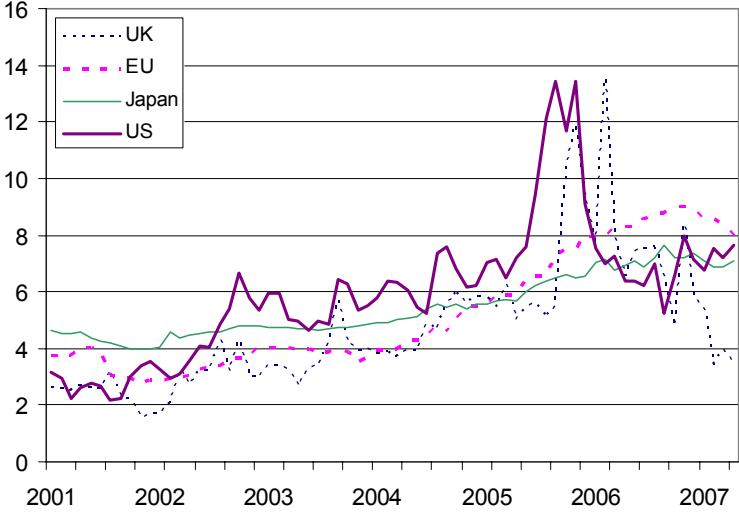
In this paper we investigate how lower transport costs for natural gas may affect the international gas markets. We explore how the natural gas prices (i.e., wellhead or producer prices) in different regions change when the costs of LNG or pipeline transport are reduced. In a case with only two (geographical) markets/regions, lower transport costs normally increase the trade volumes, reducing the price differential between the regions as the export market price increases and the import market price decreases. However, with more than two markets, the effects are less straightforward. We show, using both theoretical and numerical tools, that counterintuitive effects may appear. That is, prices in import (export) markets may possibly increase (decrease) when transport costs are reduced, and price differentials between two import regions may increase. The outcome depends largely on transport distances and choice of transport technology.

Our analysis presumes that the international gas markets are liberalised and integrated, so that transport cost reductions generate a new market equilibrium with modified trade pattern and price levels. However, whereas the North American gas market is deregulated and prices have been linked to liquid spot markets for almost two decades, most of the European and the North-East Asian gas markets are still indexing the price of almost all their gas volumes to various oil products through long-term contracts. As gas competes in the end-user markets with other energy goods such as oil and coal, which are globally traded, there are indirect links between regional gas markets even in the absence of gas trade. Nevertheless, Siliverstovs et al. (2005) find no sign of price integration between the North American market and the European/Japanese markets in the period 1994-2003.<sup>1</sup> As seen in Figure 1, price differentials between e.g. North America and Europe have been highly volatile through the years, especially in the short term. However, the arbitrage trade options have not been sufficient to level the price differences, partly due to the rigidity of the fixed contracts and partly due to the high transportation costs.

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<sup>1</sup> Several studies have examined intra-regional price integration within Europe (Asche et al., 2002, Micola and Bunn, 2007, Robinson, 2007) or the US (e.g., Kleit, 1998, Serletis and Herbert, 1999, Marmer et al., 2007). They generally find that gas prices are integrated as long as transmission capacities are sufficient.

**Figure 1: Monthly natural gas prices in different regions (\$/mbtu)**



Source: World Gas Intelligence and Energy Information Administration

Although several obstacles remain before the international gas markets are fully integrated like the oil market, the current trends are clearly directed towards globalisation of gas markets. International spot trade of gas is growing rapidly, by a factor of 10 since 1998 according to IEA (2006). Although it accounted for just 11 per cent of international trade in 2004, it is expected to double in a few years. Spot trade makes it easier for gas sellers to enter markets where long-term contracts previously have dominated the trade volumes. Hence, short-term price differentials may be exploited, possibly leading to increased price convergence between regions. In fact, a moderate level of spot trade based on arbitrage may be sufficient to balance the markets in different regions (Jensen, 2004). So far, most arbitrage trading has occurred in the Atlantic Basin, but recently the Middle East has become a swing supplier to both North-East Asia and the Atlantic Basin. Alongside increased spot trade, gas markets are gradually becoming more competitive and deregulated, also outside North America. This is particularly so in Europe, where the UK liberalised its gas market around 1990, and the EU has adopted two directives on gas liberalisation over the last decade (EU, 1998, 2003).

Our study relates to the theoretical literature on pricing and regulation of gas transport, which is a crucial matter in natural gas markets, partly because transport costs constitute a large share of total delivery costs for natural gas. There exist a number of studies on this issue. Newbery (1999) presents theories of regulation of networks in general, and discusses the main characteristics and the history of regulation of gas markets. Cremer et al. (2003) derive a number of theoretical results regarding first- and second-best tariffs in a triopolistic market (i.e., a three-nodes network). First-best tariffs equal marginal transportation costs with a mark-up when the line is congested, whereas second-best tariffs also involve Ramsey corrections. Cremer and Laffont (2002) examine how unregulated market power

affects the socially optimal capacity of the network, whereas Hagen et al. (2004) address the question of optimal tariffs when all the gas is exported. Within a triopolistic market, Mizuno and Shinkai (2006) investigate firms' incentives to invest in network infrastructure through coalition formation, and the regulatory implications of this.

In our paper we first derive a theoretical, triopolistic model to study the effects of lower transport costs on natural gas prices. Although the analysis is quite simple, it offers new insight into the literature on gas transportation, which so far has focused mainly on network regulation and tariff design. The latter topics are particularly relevant for pipeline transport, which is the dominant transport form when it comes to intra-regional trade. Although most of the internationally traded gas is still transported through pipelines, the share of LNG transport is rising rapidly, especially at long distances, and LNG offers more flexibility than pipelines in transport services. Consequently, as trading is less dependent on site-specific capacities (regasification capacities are seldom fully utilised, cf. Jensen, 2003), LNG makes it easier to exploit arbitrage opportunities, increasing the relevance of this study.

Second, we apply a detailed numerical model of the international gas markets to investigate the effects of transport cost reductions for either LNG or pipelines. In line with the theoretical analysis, we focus on gas prices and particularly examine whether prices in the main import regions fall or not. We also look at the effects on price convergence between import regions. The model (FRISBEE) distinguishes between 13 geographical regions, and specifies bilateral trade between each pair of regions. It also has a detailed modelling of gas production, based on e.g. gas endowments in the different areas.

Most earlier numerical analyses of natural gas markets have focused on one specific region, which is not surprising given the separation of regional markets historically. Golombek et al. (1995, 1998), Boots et al. (2004) and Egging and Gabriel (2006) analyse different aspects of market power in the European gas market (including Russia and North Africa). Hirschhausen et al. (2005) and Sagen and Tsygankova (2006) examine how respectively Russian transport strategies and domestic price policy affect the export of gas from Russia to Europe. MacAvoy and Moshkin (2000) and Gabriel et al. (2000, 2005) simulate the North American gas market, focusing on further deregulation, Canadian carbon policy, and the potential for market power, respectively. EMF (2007) presents future scenarios of the international gas markets based on several global and regional simulation models (including FRISBEE). As far as we know, there exist no other papers in international journals presenting simulations of the global natural gas markets. The numerical analyses presented in this paper are therefore quite original compared to earlier studies, and timely given the globalisation process noted above. Moreover, no studies have so far looked at the effects of lower transport costs in a global context, except for Brito and Hartley (2007) mentioned above.

The theoretical analysis is presented in the following section. In Section 3 we briefly describe the numerical model FRISBEE. Then we present the simulation results in Section 4, before concluding in the last section.

## 2. Theoretical analysis of transportation costs and gas prices

In this section we introduce a simple theoretical approach to study how transport cost reductions affect gas prices in different regions of the world. We will take into account that gas may be transported in different ways (LNG or pipeline transport), so that cost reductions may or may not affect all gas trade. Moreover, some transport costs are increasing with distance (pipeline and shipping costs), and some are not (liquefaction and regasification). We use a classical three-node model, also adopted in e.g. Cremer et al. (2003). They find that in a gas network with unidirectional flows, the efficient transportation charges are functions of the distance between the sub markets. In our analysis we show (among other things) that transport distances are very important for how regional gas prices may react to transport cost reductions. Although the global gas market consists of more than three regional markets that produce and consume natural gas, the main findings in our theoretical model may also be relevant in a more general setting.

### 2.1 Model setup and market equilibrium

We assume there are three different regional natural gas markets,  $A$ ,  $B$  and  $C$ . All market participants are assumed to be price-takers. Each region has supply and demand functions depending on its domestic price  $p_i$ :

$$(1) \quad y_i = \alpha_i(p_i)$$

$$(2) \quad x_i = \beta_i(p_i) \quad i = A, B, C,$$

where  $\alpha'_i > 0$  and  $\beta'_i < 0$  define the regional price responsiveness of supply and demand, respectively.

We further assume that natural gas trade takes place between these regions only; hence we have the following inter-regional market equilibrium:

$$(3) \quad \sum_i y_i - \sum_i x_i = \sum_i \alpha_i(p_i) - \sum_i \beta_i(p_i) = \sum_i (\alpha_i(p_i) - \beta_i(p_i)) = 0.$$

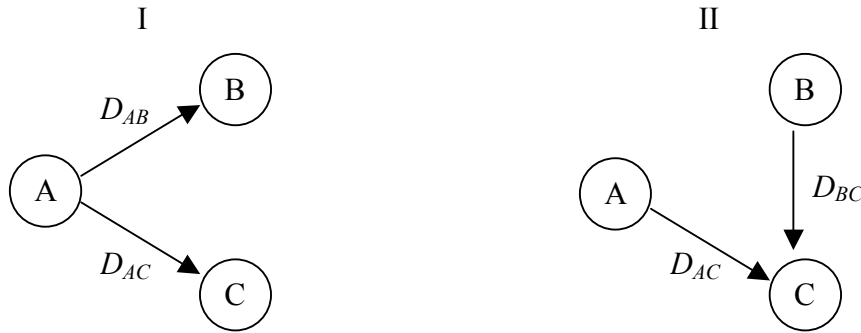
We assume that transport costs are strictly positive, and proportional with transported volume of gas. This is not always realistic in the short run, because of possible capacity constraints when capacities of pipelines and LNG terminals are fixed and capital costs are sunk. However, in the long run we think it is a reasonably good approximation when both capital and operating costs are considered. Transport



tariffs  $T_{ij}$  are assumed equal to the constant unit costs. In this simple model there will be unidirectional (if any) trade between a pair of regions, that is, a region will not both import and export natural gas from/to the same region. Furthermore, to simplify the presentation we disregard transit trade, assuming that  $T_{ik} < T_{ij} + T_{jk}$ .<sup>2</sup>

Let  $A$  denote the region with the lowest domestic price, and  $C$  the region with the highest price ( $p_A < p_B < p_C$ ). Price differentials may arise from different gas supply costs or different demand structure, which lead to inter-regional gas trade. Assuming that all three regions participate in gas trade, we have the following two possible trade patterns in a standard three-node model, where  $D_{ij}$  denotes the transport distance between region  $i$  and region  $j$ :

**Figure 1. Trade patterns in three-node model**



- I An "export pattern", where region  $A$  exports gas to both regions  $B$  and  $C$ .
- II An "import pattern", where region  $C$  imports gas from both regions  $A$  and  $B$ .

The trade patterns above may be exemplified by current natural gas trade. For instance, with the export pattern, we can think of export region  $A$  as the Middle East, the closest import region  $B$  as Europe, and the most distant import region  $C$  as North America.

We now assume that unit transport costs can be divided into a fixed unit cost independent of distance ( $T_{ij}^F$ ), and a unit cost proportional with distance ( $T_{ij}^D$ ). This is particularly important for LNG, where the first component may refer to liquefaction and regasification costs, and the latter component to shipping costs (for pipelines the first component may be negligible). The cost parameters  $T_{ij}^F$  and  $T_{ij}^D$  may differ between pair of regions (e.g., if different transport technologies are used), or they may be identical (e.g., if only LNG transport is used).

<sup>2</sup> We may also have the special case where the equation holds with parity, which means that one of the regions serves as a pure geographical transit region for trade between the two other regions.

Assuming that all arbitrage possibilities from trade are utilised, we get the following price equations for the "export pattern":

$$(4) \quad p_A + D_{AB}T_{AB}^D + T_{AB}^F = p_B$$

and

$$(5) \quad p_A + D_{AC}T_{AC}^D + T_{AC}^F = p_C,$$

while for the "import pattern" equation (5) still holds together with the following one:

$$(6) \quad p_B + D_{BC}T_{BC}^D + T_{BC}^F = p_C.$$

From equations (4)-(6) it is straightforward to see that with the "export pattern", prices are lowest in region  $A$  and highest in the region with the largest transport costs from region  $A$ . Moreover, we see that the "import pattern" is just a mirror image of the "export pattern". Note that the price rankings are completely independent of supply and demand conditions in the regions (given the trade directions and no transport capacity constraints).

We now want to examine the potential effects on prices in each of the regions following changes in the unit transport costs. Much attention has been paid to cost reductions in natural gas transport in general and for LNG in particular, and we find it important to take a closer look at the regional price effects of such cost reductions. We assume that the reductions in cost do not affect the trade directions.

## 2.2 Effects of transport cost reductions

We examine the "export pattern", that is when region  $A$  exports to both region  $B$  and  $C$ , and relegates the "import pattern" results to Proposition 1 at the end of this section. We will consider four cases, i.e., reductions in the i) fixed unit transport cost for one pair of regions ( $T_{AB}^F$ ), ii) fixed unit transport cost for both pair of regions ( $T_{Aj}^F$ ), iii) distance-related unit transport cost for one pair of regions ( $T_{AB}^D$ ), and iv) distance-related unit transport cost for both pair of regions ( $T_{Aj}^D$ ).

First we differentiate equation (3):

$$(7) \quad \sum_i (\alpha'_i(p_i) - \beta'_i(p_i)) dp_i = 0.$$

Starting with export region  $A$ , we further differentiate equations (4) and (5), insert into (7) and rearrange:

$$(8) \quad \sum_i (\alpha'_i(p_i) - \beta'_i(p_i)) dp_A = - \sum_{j \neq A} [(\alpha'_j(p_j) - \beta'_j(p_j)) (D_{Aj} dT_{Aj}^D + dT_{Aj}^F)].$$

We are now ready to investigate the impacts on the export price from the four different types of transport cost reductions:

$$(9) \quad -\frac{dp_A}{dT_{AB}^F} = \frac{\alpha'_B(p_B) - \beta'_B(p_B)}{\sum_i (\alpha'_i(p_i) - \beta'_i(p_i))} > 0 \quad (\text{case i})$$

$$(10) \quad -\frac{dp_A}{dT_{Aj}^F} = \frac{\sum_{j \neq A} (\alpha'_i(p_i) - \beta'_i(p_i))}{\sum_i (\alpha'_i(p_i) - \beta'_i(p_i))} > 0 \quad (\text{case ii})$$

$$(11) \quad -\frac{dp_A}{dT_{AB}^D} = \frac{(\alpha'_B(p_B) - \beta'_B(p_B))D_{AB}}{\sum_i (\alpha'_i(p_i) - \beta'_i(p_i))} > 0 \quad (\text{case iii})$$

$$(12) \quad -\frac{dp_A}{dT_{Aj}^D} = \frac{\sum_{j \neq A} [(\alpha'_i(p_i) - \beta'_i(p_i))D_{Aj}]}{\sum_i (\alpha'_i(p_i) - \beta'_i(p_i))} > 0. \quad (\text{case iv})$$

Not surprisingly, we see that the exporting region  $A$  will experience increasing domestic prices when transportation costs fall, regardless of which case we consider, and that the price increase is highest if there are transport cost reductions to both import regions. We also see that the size of the price effect is positively dependent on the price responsiveness in supply and demand in the import market(s) that is directly affected by lower transport costs. Conversely, the price effect is negatively dependent on the price responsiveness in the export market and (if relevant) the import market that is not directly affected by lower transport costs. The reason is that the reduced price differential between the export and the import region(s) is fixed by the transport cost reduction. Thus, if the import region(s) is very price responsive, and the export region is not, most of the reduced price differential will end up as higher price in the export region.<sup>3</sup> Finally, we see that if the distance-related transportation costs are reduced, the distance(s) between the export and the import market(s) also affects the price reduction positively.

If we look at the import markets, the price effects from transport cost reductions are not always clear-cut. Again we differentiate equations (4) and (5), insert into (7) and rearrange:

$$(13) \quad \begin{aligned} & \sum_i (\alpha'_i(p_i) - \beta'_i(p_i)) dp_B \\ & = \sum_{j \neq B} (\alpha'_j(p_j) - \beta'_j(p_j)) (D_{AB} dT_{AB}^D + dT_{AB}^F) - (\alpha'_C(p_C) - \beta'_C(p_C)) (D_{AC} dT_{AC}^D + dT_{AC}^F). \end{aligned}$$

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<sup>3</sup> Note that an import market not directly affected by transport cost reductions will have unchanged price differential with the export region, and thus price responsiveness in this region has the same effect as price responsiveness in the export market.

With respect to case i) and iii) referred to above, we now have to distinguish between cost reductions for transport between  $A$  and  $B$  (cases i-a and iii-a), and between  $A$  and  $C$  (cases i-b and iii-b). We then get the following price effects in import region  $B$  in the six different cases:<sup>4</sup>

$$(14) \quad -\frac{dp_B}{dT_{AB}^F} = -\frac{\sum_{i \neq B} (\alpha'_i(p_i) - \beta'_i(p_i))}{\sum_i (\alpha'_i(p_i) - \beta'_i(p_i))} < 0 \quad (\text{case i-a})$$

$$(15) \quad -\frac{dp_B}{dT_{AC}^F} = \frac{\alpha'_C(p_C) - \beta'_C(p_C)}{\sum_i (\alpha'_i(p_i) - \beta'_i(p_i))} > 0 \quad (\text{case i-b})$$

$$(16) \quad -\frac{dp_B}{dT_{Aj}^F} = -\frac{(\alpha'_A(p_A) - \beta'_A(p_A))}{\sum_i (\alpha'_i(p_i) - \beta'_i(p_i))} < 0 \quad (\text{case ii})$$

$$(17) \quad -\frac{dp_B}{dT_{AB}^D} = -\frac{\sum_{i \neq B} (\alpha'_i(p_i) - \beta'_i(p_i)) D_{AB}}{\sum_i (\alpha'_i(p_i) - \beta'_i(p_i))} < 0 \quad (\text{case iii-a})$$

$$(18) \quad -\frac{dp_B}{dT_{AC}^D} = \frac{(\alpha'_C(p_C) - \beta'_C(p_C)) D_{AC}}{\sum_i (\alpha'_i(p_i) - \beta'_i(p_i))} > 0 \quad (\text{case iii-b})$$

$$(19) \quad -\frac{dp_B}{dT_{Aj}^D} = -\frac{\sum_{i \neq B} (\alpha'_i(p_i) - \beta'_i(p_i)) D_{AB} - (\alpha'_C(p_C) - \beta'_C(p_C)) D_{AC}}{\sum_i (\alpha'_i(p_i) - \beta'_i(p_i))} \gtrless 0 \quad (\text{case iv})$$

When transport cost reductions take place for only one pair of regions (cases i and iii), the price effect is unambiguous. That is, if transport costs to region  $B$  are reduced, but not to region  $C$ , prices are definitely reduced in region  $B$ , and increased in region  $C$  (and vice-versa). This is relevant if LNG is used between one pair of regions (e.g., Middle East and North America), and pipeline is used between the other pair of regions (e.g., Middle East and Europe). Hence, assuming  $p_B < p_C$ , there will be price convergence between the importing regions if transport costs are reduced between regions  $A$  and  $C$  only, and price divergence if transport costs instead are reduced between regions  $A$  and  $B$ . Note that if  $B$  and  $C$  are switched in equations (15) and (18), the size of the price effects in cases i-b) and iii-b) are identical to the export price effects in equations (9) and (11). This is due to the unchanged price differential between regions  $A$  and  $C$  in these cases.

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<sup>4</sup> The price effects in region  $C$  can be found by switching  $B$  and  $C$  in the equations.

If the fixed unit cost of transport is reduced for both pair of regions (case ii), the price definitely falls in both import regions, and the price reduction will be identical for the two regions (the distances to the markets have no bearing on the effect). This will be the situation if LNG is used to both import regions and liquefaction costs are reduced. In this case there will be neither price convergence nor divergence between the import markets.

Finally, if the distance-related transport costs are reduced for both pair of regions (case iv), the price effect is ambiguous, at least for the region closest to the export region. This is relevant if LNG (pipeline) is used for both pair of regions, and shipping (pipeline) costs decrease. However, for the region most distant from the export region (e.g., North America), the price clearly falls. This is seen by switching  $B$  and  $C$  in equation (19), assuming  $D_{AB} < D_{AC}$ .

On the other hand, we may have *increased* prices in region  $B$  (e.g., Europe) when distance-related transport costs are reduced, even if the same transport technology is used to both regions. The intuition is that if the distance between regions  $A$  and  $C$  is very long, transport cost reductions will be substantial and have a significant effect on price convergence between these two regions. Consequently, the price increase in the export region may be large, and possibly larger than the transport cost reduction between regions  $A$  and  $B$ . If so, the price in region  $B$  also rises. To what degree the price convergence between regions  $A$  and  $C$  leads to higher price in region  $A$ , depends on the price responsiveness in these two regions (as mentioned before). Furthermore, if the distance between regions  $A$  and  $B$  is short, price convergence between these two regions will be modest, increasing the likelihood of higher price in region  $B$ . In any case, there will be price convergence between the importing regions when the distance-related transport costs fall.

We sum up our main results in the following proposition:

**Proposition 1.**

In a three-node “export pattern” market with constant unit costs of transport, we get the following price effects of transport cost reductions:

- i) The price in an export region increases whatever transport costs are reduced, and there will be price convergence between the export and import region(s) directly affected by cost reductions.
- ii) The price in an import region decreases if the transport cost reduction only takes place between the export region and the import region in question, but *increases* if the transport cost reduction only takes place between the export region and the other import region.
- iii) The price in an import region decreases if the fixed unit transport cost declines for both transport routes.

- iv) The price in an import region decreases if the distance-related unit transport cost declines for both transport routes and the import region in question is most distant from the export region.
- v) The price in an import region may either decrease or increase if the distance-related unit transport cost declines for both transport routes, and the import region in question is nearest to the export region. Relative distances and price responsiveness in supply and demand in the export region and the other import region will then determine the direction of change in the price.
- vi) There will be price convergence between the import regions unless cost reductions only take place between the export region and the import region with the lowest price (in which case there will be price divergence), or unless the fixed unit transport cost declines for both pair of regions (in which case there will be no price convergence/divergence).

Most of the results are not surprising at all, but the finding in part v) of Proposition 1 is quite counterintuitive at first glimpse. One example of this case may be if shipping costs fall and both Europe and North America import LNG. As the proposition states, we may observe *higher* prices in Europe in this case. The finding in part vi) about price divergence may also be noteworthy, although not really surprising. One example of price divergence may occur if Europe imports pipeline gas and North America imports LNG, and only pipeline costs fall.

As mentioned in the beginning of this section, the “import pattern” is just a mirror image of the “export pattern” analysed above. Thus, in an “import pattern” market Proposition 1 holds if we switch the words ‘export’ and ‘import’ and (price) ‘increase’ and ‘decrease’.

### **3. FRISBEE – A model of international energy markets**

We now want to examine the effects of reduced transport costs within a numerical model of the international gas markets. In this section we briefly present the FRISBEE model, which is applied for our numerical analyses. Then we discuss the results in the next section.

The FRISBEE model is a recursive, dynamic partial equilibrium model of the international energy markets.<sup>5</sup> Supply and demand of fossil fuels and electricity are modelled in 13 global regions, cf. Table 1. The model accounts explicitly for discoveries, reserves, field development and production of oil and natural gas in each region. Coal and electricity production are modelled in a more simple way.

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<sup>5</sup> A more extensive presentation of the FRISBEE model system is offered by Aune et al. (2005). Aune et al. focus on the oil market, but natural gas supply (and demand) is modelled quite similarly as oil supply, so most equations carry over. The main modelling difference is related to trade between regions, which we focus on in this study. As we model bilateral trade of natural gas, we handle the OPEC regions differently than in the oil module (i.e., the OPEC members Venezuela and Indonesia are treated as a part of “Latin America” and “Rest-Asia”, respectively).

Demand for energy is divided into three sectors of the economy: ‘Manufacturing industries’, ‘Power generation’, and ‘Others’ (including household consumption). The energy markets are assumed to clear in each period (year). Regional supply, demand, prices and trade flows on an annual basis are among the outputs of the model.<sup>6</sup>

**Table 1. Regions in the FRISBEE model**

<i>Industrialised regions</i>	<i>Regions in transition</i>	<i>Developing regions</i>
Canada	Caspian region	Africa
OECD Pacific	Eastern Europe	China
USA	Russia/Ukraine/Belarus	Latin America
Western Europe		OPEC-Middle East
		Rest-Asia
		OPEC-Africa

Demand for any energy good in the model depends on the end-user prices of all energy goods. For natural gas, the direct price elasticities for ‘Manufacturing industries’ and ‘Others’ are on average around -0.3 in the long run, and around -0.1 in the short run (cf. Liu, 2004), whereas cross-price elasticities are much smaller. Income growth is particularly important in the longer term, with (per capita) income elasticities on average around 0.6. Population growth and exogenous energy efficiency are also affecting energy demand. In the ‘Power generation’ sector, fuel demand is driven by existing power capacities and generation costs for different thermal plants, as well as the electricity price. Thus, substitution possibilities are much higher here than in the two end-user sectors. For existing capacities, only operating costs and fuel input prices matter for the production decision. For new capacities, capital costs must also be covered.

Natural gas markets are assumed to be fully competitive, both upstream and downstream. There are of course some big players in the current market, such as Russia that holds one quarter of the global gas reserves. However, Russian export only constitutes about 5 per cent of global production (BP, 2007), whereas domestic consumption in Russia is more than two times higher than its export. In Europe, Russia has a market share of about 25 per cent, but its market power gradually declines in line with the globalisation process, e.g., due to more LNG trade from distant sources. Thus, although competitive producers are a simplification of the current market structure, we believe that this is of lesser importance for our study.

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<sup>6</sup> The model abstracts from seasonal variations in demand and supply. Thus, variations in e.g. trade direction over the year are not captured by the model..

Natural gas markets in Europe and Japan have traditionally been highly regulated, whereas the North American (and the UK) market(s) have been liberalised for some time. However, according to IEA (2006), there is a general trend towards liberalisation across OECD regions (including EU and Japan), and this trend is spreading to non-OECD regions as well. Long-term contracts with gas prices linked to the oil price have been dominant, but the extent of spot trade and gas price indexation in long-term contracts is growing rapidly (Cornot-Gandolphe, 2005). In the FRISBEE model there is no formal link between oil and gas prices, but as oil and gas are (imperfect) substitutes on the demand side, the prices (of all fossil fuels) are partially connected.

The development of natural gas (and oil) production in the model is influenced by initial production capacity, and investments in finding new discoveries, field development, and reserve extensions from developed fields. Production volumes from developed fields are determined by the equalisation of marginal producer costs to producer (wellhead) prices in each region. Investments are driven by expected returns, and net present values are calculated for four field categories in each of the 13 regions (i.e., 52 field groups), based on adaptive price expectations and a pre-specified required rate of return (which is set to 10 per cent in real terms). Data on production costs and field characteristics are based on an extensive database of global petroleum reserves in the year 2000.

Investments in field development and reserve extension projects are based on the following maximisation problem:

$$(20) \quad \text{Max}_{R_{I,j}} \Pi^e \left( R_{I,j}, P_j^{E,I}, r, C_{O,j}, C_{C,j}, GT_j, NT_j, \bar{F}_j \right),$$

where  $R_{I,j}$  denotes the level of gas reserves that are either developed or generated through reserve extension projects in field group  $j$ ,  $P_j^{E,I}$  is expected (real) price to the producers for investment activity  $I$  in field group  $j$ ,  $r$  the required rate of return,  $C_{O,j}$  and  $C_{C,j}$  unit operating and capital costs, respectively,  $GT_j$  and  $NT_j$  gross and net tax rates on natural gas production, respectively, and  $\bar{F}_j$  is a vector of field characteristics that differ across field groups (notably decline rate and time lags). Note that capital costs are increasing in the level of activity, decreasing in undeveloped reserves (for new fields), and increasing in the recovery rate (for reserve extension).

New discoveries are modelled more simply, but depend on the expected gas price and expected undiscovered gas reserves in each region, mainly based on USGS (2000). Nevertheless, we assume that the less costly fields in each region are developed first. Hence, despite a moderate technological



progress, unit production costs will increase over time, which will also result in an increasing price trend.

FRISBEE models bilateral trade of natural gas between pair of regions. Unit costs (or tariffs) of LNG and pipelines are assumed to be constant within a period, and reflect both capital and operating costs. One exception is existing pipeline capacities before 2007, where unit costs only reflect operating costs. There are no constraints (physical, economic, geopolitical etc.) related to investments in new transportation capacity if it is profitable for the exporter. In each period (year), either LNG or pipeline is used as the preferable transport technology between two regions, depending on which technology has the lowest overall costs. Thus, an export (import) region can use both LNG and pipeline transport, but not to (from) the same import (export) region.<sup>7</sup> However, the choice of transport method may change over time due to reductions in transport costs.

With this modelling of gas trade, where all arbitrage opportunities are fully exploited, the (producer) price differential between a pair of regions cannot exceed the unit transport cost between the two regions. On the other hand, if the price differential is less than the unit transport cost, there will be no trade between the two regions. Consequently, the price in an import region will be exactly equal to the price in the region(s) from which it imports gas *plus* the unit transport costs between the two regions. Thus, we have (cf. Kleit, 1998):

$$(21) \quad (\Delta P_{ij} - T_{ij})Z_{ij} = 0 \quad \text{and} \quad \Delta P_{ij} \leq T_{ij}$$

where  $\Delta P_{ij} = |P_i - P_j|$ ,  $P_i$  is producer price in region  $i$ ,  $T_{ij}$  is unit transport cost between regions  $i$  and  $j$ , and  $Z_{ij}$  is export volume between regions  $i$  and  $j$ .

Data on transport costs are mainly based on OME (2001). Total transportation costs, for both pipeline and LNG, are functions of fixed and variable unit costs and the distance between the regions.

The base year of the model is 2000. The model is programmed in GAMS (Brooke et al., 1998).

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<sup>7</sup> This is of course a simplification of the real world trade, where e.g. Algeria exports gas to Western Europe by both pipelines and LNG. The mix of pipelines and LNG between two regions may be a consequence of different geographical locations for import to (or export from) a region, different levels of flexibility for the two transport forms, or simply sunk costs for invested capacity. These features are not captured by the model, and so our conclusions should be interpreted with some caution.

# 4. Numerical model results and discussion

## 4.1 The reference case and scenario description

In this section we present the model results, referring to our main research question stated earlier: How will lower transport costs for natural gas affect the international gas markets? To examine this issue we have run three different model scenarios with different LNG-chain or pipeline cost reductions, presented in Table 2 below. In each of the scenarios, costs are reduced by 4 per cent each year throughout the model horizon relative to a reference case with constant costs. The model is run from 2000-2030, which means that costs are reduced by 70 per cent in 2030 compared to the reference case. This may be seen as a radical change, particularly for pipeline costs, but it is used to illustrate the potential market effects from substantial cost reductions. According to EIA (2004), liquefaction costs were reduced by 35-50 per cent over the preceding ten years, whereas shipping costs have fallen by about 40 per cent over the last ten years (Brito and Hartley, 2007). We will concentrate our discussions of each scenario around the producer price changes and trade patterns relative to the reference case.

**Table 2: Different scenarios of natural gas transport cost reductions**

Scenario "Liq"	Scenario "Ship"	Scenario "Pipe"
LNG liquefaction cost reduction (4% p.a. from 2000)	LNG shipping cost reduction (4% p.a. from 2000)	Pipeline cost reduction (4% p.a. from 2000)

Reduced transportation costs within an industry are often associated with lower import prices. However, in a situation with more than two regions our theoretical analysis has shown that this is not always the case. In our discussions below we will follow up on our theoretical examination of the "export pattern" by focusing on the price-trade relationships between three of the most important model regions; OPEC-Middle East (hereafter M-E) as an export region, and Western Europe (hereafter W-E) and North America (USA and Canada, hereafter N-A) as import regions.<sup>8</sup> As much attention has been paid to the increasing arbitrage-driven gas trade in the Atlantic basin, we particularly focus on this part of the gas market. From our theoretical analysis, we should expect the producer prices in N-A

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<sup>8</sup> As seen in Table 1, USA and Canada are two distinct regions in the model. Thus, when we present prices in N-A, we report US prices. When we present volumes of gas, we consider N-A together, i.e., ignoring trade between USA and Canada.

to be higher than in W-E due to longer transport distance from the exporting region.<sup>9</sup> Figure 2, presenting producer prices in the reference case, confirms this hypothesis.<sup>10</sup>

**Figure 2. Producer prices in the reference case (\$2000/toe)**

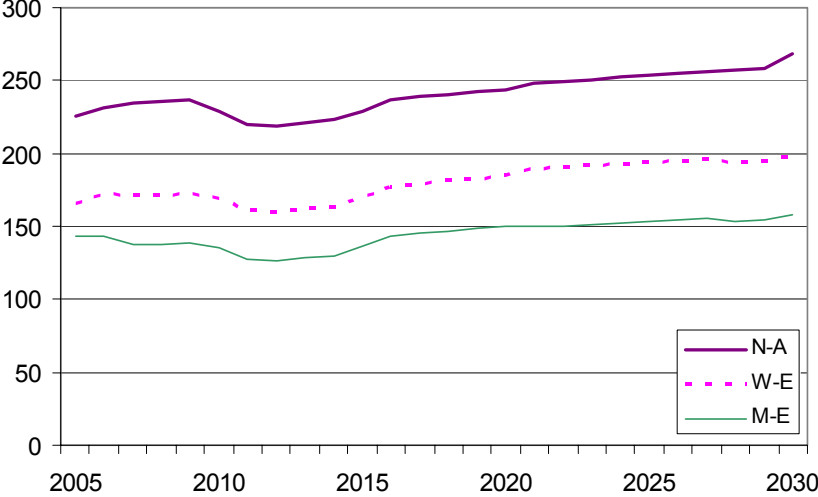


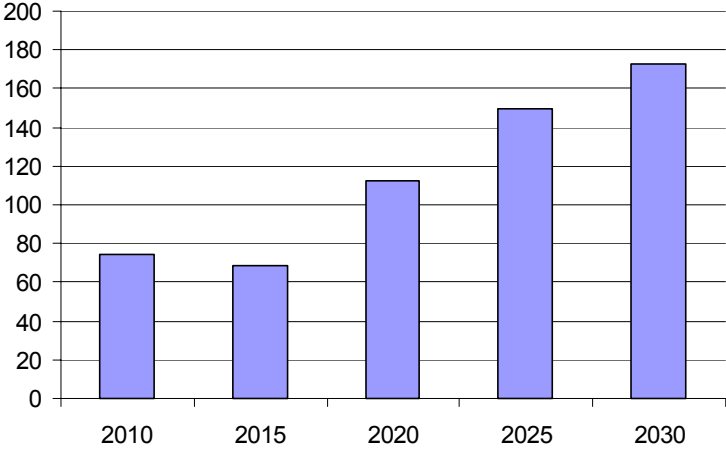
Figure 2 shows an upward trend in the gas price, at least from 2012, for all the three model regions in the reference case, which is what we would expect in a market with gradual depletion of a non-renewable resource. Moreover, we find that producer prices in N-A are higher than in W-E, while M-E has the lowest prices. This is a combined result of longer distances to the N-A market and more (pipeline) supply options to the W-E market.<sup>11</sup> That is, with continuously depleting reserves in North America, and LNG as the only import option, we would expect transatlantic trade to grow over time, which is confirmed by our reference case results in Figure 3.

<sup>9</sup> Obviously, M-E is not the only exporting region in FRISBEE, or in the real world. In particular OPEC-Africa, primarily represented by Algeria and Nigeria, may produce significant volumes of gas directed to the N-A (LNG) and/or the W-E (LNG and pipeline) gas markets. In addition, Russia is a main pipeline gas supplier to W-E, and also has ambitions to be a large-scale LNG supplier from its gas fields in the Barents Sea. This, however, will not change the intuition behind our results, as the average distance from both OPEC-Africa and Russia to N-A is longer than the respective distances to W-E. In addition, there are several questions related to Russia's ability to increase or even stabilize their export volumes in the future. Sagen and Tsygankova (2006) find that continuously low gas prices in Russia and/or failure to increase Russian production capacities, may hinder growth and even lead to reductions in future exports towards Europe.

<sup>10</sup> As seen from Figure 1, this has also been the case historically, except for the last 1-2 years.

<sup>11</sup> W-E imports pipeline gas from both OPEC-Africa (e.g. Algeria) and Russia, which is less costly than LNG. N-A obviously has to rely on LNG as its only import source. However some LNG also come from Latin America (e.g. Trinidad & Tobago, Bolivia and Venezuela).

**Figure 3. Transatlantic trade per year to the N-A market in the reference case (Mtoe)**

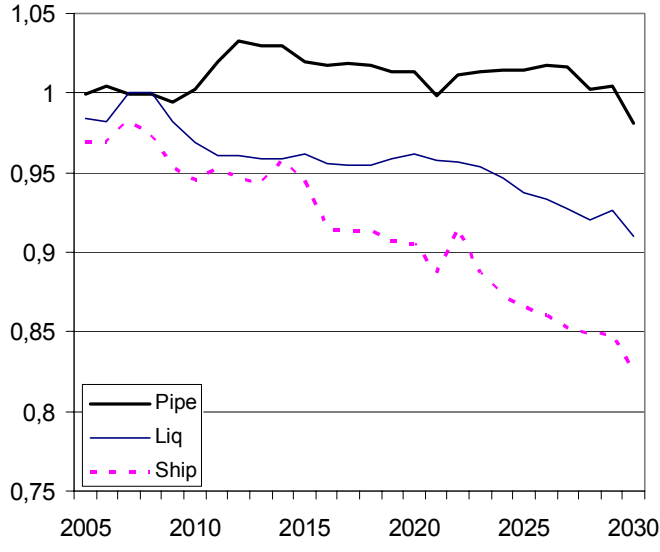


Before we look at the numerical effects of lower transport costs, let us consider what to expect based on the theoretical analysis above. To recap, we have a situation with one purely LNG-importing region (N-A) and one region (W-E) that mainly imports via pipelines (but with potential for LNG-import). According to our theoretical findings, we should expect prices to decrease in N-A if LNG costs are reduced, due to the longer transport distance to this market than to other markets. For W-E, which mainly imports via pipelines, we should expect higher prices in this case unless LNG takes significant market shares. However, even then the short distance to the export region may contribute to higher prices, but this will depend on the price responsiveness in the different markets and what cost component is reduced. On the other hand, if pipeline costs fall, this should imply lower prices in W-E and higher prices in N-A. For M-E we should expect higher prices in all scenarios.

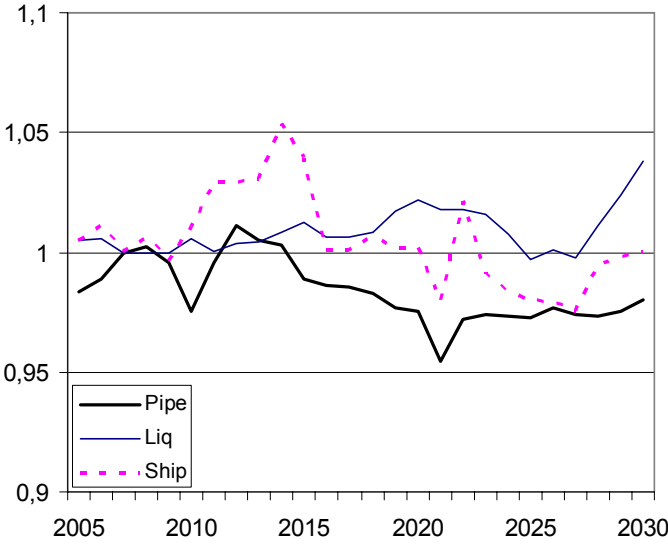
**4.2 Price effects following transport cost reductions**

The model simulations largely support our expectations based on the theoretical findings. Figures 4-7 show price changes relative to the reference case for all scenarios in N-A, W-E and M-E, as well as OPEC-Africa, which is commented on below.

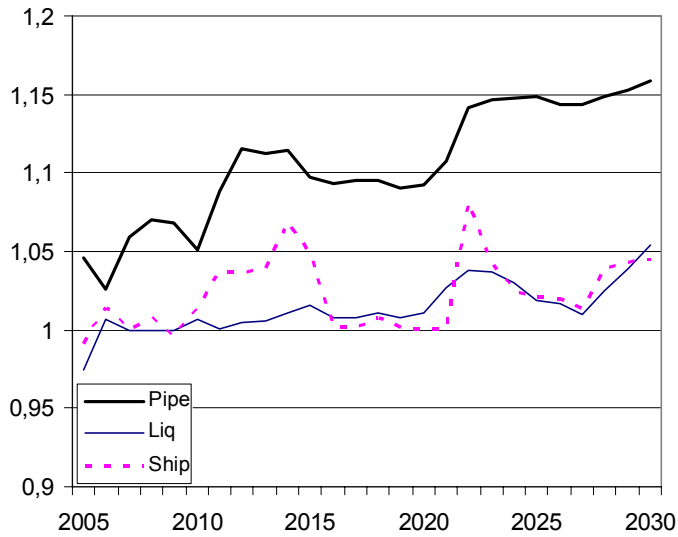
**Figure 4. Gas prices relative to the reference case. North America**



**Figure 5. Gas prices relative to the reference case. Western Europe**



**Figure 6. Gas prices relative to the reference case. Middle East**



**Figure 7. Gas prices relative to the reference case. OPEC-Africa**

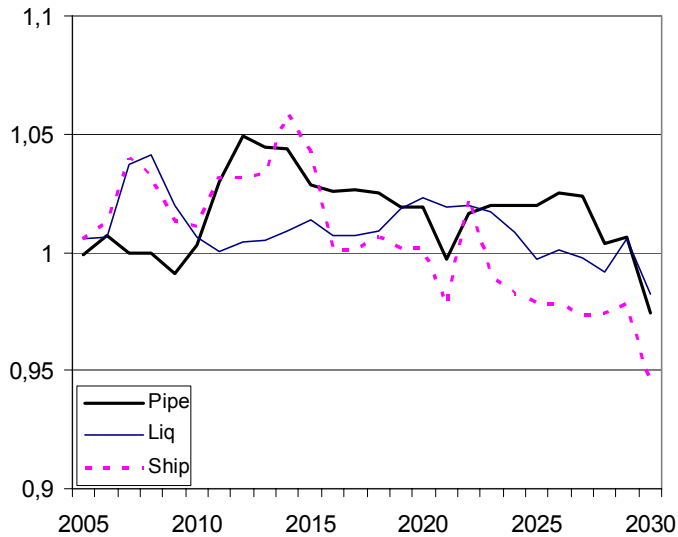


Figure 4 clearly shows that for any reduction in the cost of LNG, prices in North America will fall. Cost reductions in the shipping segment have a larger effect than cost reductions in liquefaction, as shipping costs constitute the largest cost share at long distances. On the other hand, prices in N-A increase slightly in most periods when pipeline costs are reduced (as predicted). The small decline in a couple of years is due to the fact that the gas imported to N-A can be first transported from the export region via (less costly) pipeline to a transit country (closer to N-A), and then transported as LNG over the Atlantic.

For the exporting region Middle East (see Figure 6) prices generally increase in all scenarios, as expected. However, the price response in M-E varies significantly over time, primarily due to the

varying share of LNG relative to pipeline as the preferred transport method in total M-E exports. Ignoring geopolitical concerns and assuming constant unit transport costs, pipeline export towards Europe in the west and India/China in the east, is the preferred transport option for Middle Eastern natural gas exports. Hence, the M-E producer prices are most sensitive to cost reductions in the pipeline technology. However, after cost reductions within the LNG technology, the LNG share of M-E exports increases with more exports to the N-A market. This also increases the sensitivity of M-E producer prices to overall cost reductions in the LNG sector.

For Western Europe, the price response relative to the reference case also varies noticeably over time. Moreover, the direction of the price effect is not fully clear. Yet, due to shorter distance to the export region and a lower share of LNG imports, W-E generally experiences higher prices if LNG costs fall and lower prices if pipeline costs fall.<sup>12</sup>

However, in the case with lower shipping costs, we observe that prices eventually also fall in Western Europe. This appears counterintuitive to our theoretical findings, as W-E both has a lower total share of LNG imports relative to N-A, and a shorter distance to the export region. The explanation is that W-E and N-A also import gas from other regions, most notably the African countries Nigeria and Algeria (OPEC-Africa in our model). Thus, we may alternatively consider this as an “import pattern” instead of as an “export pattern” (cf. Section 2), with N-A being the main import region. As indicated in Section 2.2, prices may fall in an exporting region following transport cost reductions if there is a short distance to the import market. This is exactly what we observe for OPEC-Africa when shipping costs fall, see Figure 7, and the lower prices in this region are passed on to W-E.<sup>13</sup>

### **4.3 Price convergence and trade**

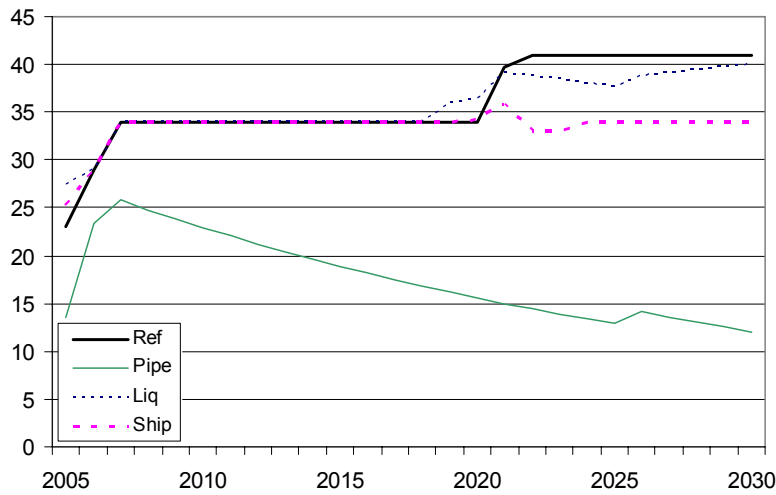
From the results behind Figures 4-7 it is straightforward to examine the relationship between transport costs reductions and inter-regional price convergence. Figures 8 and 9 show how the price differences between W-E and respectively M-E and N-A develop over time in the different scenarios. Downward sloping curves mean price convergence over time, whereas the position relative to the reference case reveals whether transport cost reductions lead to price convergence or not.

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<sup>12</sup> We have tested whether this result hinges on access to piped gas from the Middle East, and run additional simulations where all pipeline gas from the Middle East has been cut off, e.g., due to geopolitical reasons. The results show that European gas prices are still not falling following LNG cost reductions, except after 2020 in the case with lower shipping costs (just as in Figure 5). This is mainly explained by increasing pipeline supplies from North Africa, and it strengthens our findings that European gas consumers will not necessarily gain from cost reductions in the LNG sector.

<sup>13</sup> There is also a dynamic aspect here. As lower shipping costs lead to higher prices in OPEC-Africa, more gas fields are developed compared to what is the case in the reference scenario. When M-E becomes more competitive due to lower shipping costs, it is not profitable for gas producers in OPEC-Africa to cut back on production from developed fields when the price falls. Thus, export from OPEC-Africa is higher in this scenario even though prices are in general lower between 2020 and 2030.

**Figure 8: Price differential Western Europe - Middle East (\$2000/toe)**



**Figure 9: Price differential North America - Western Europe (\$2000/toe)**

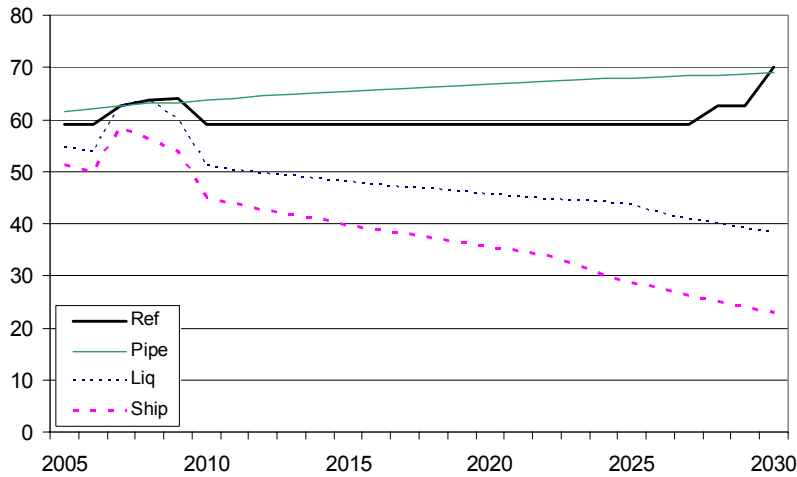
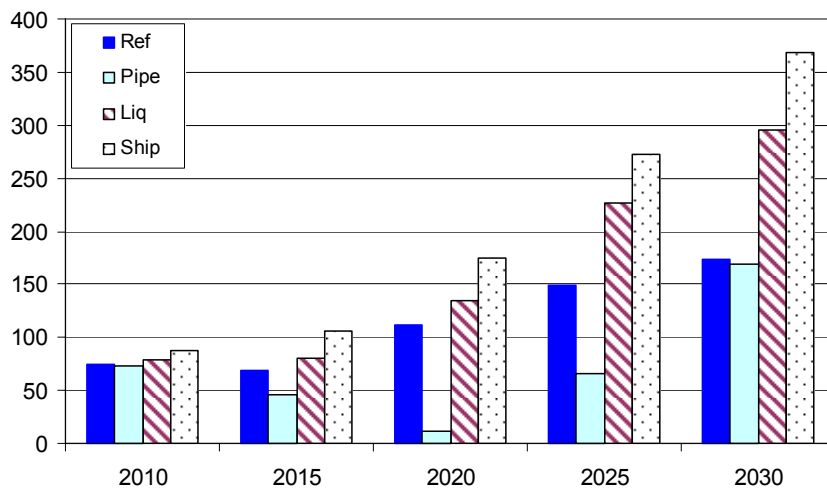


Figure 8 shows that only when pipeline costs fall, there is significant price convergence between M-E and W-E, indicating that pipeline export is the dominant transport option between these regions.

Between N-A and W-E, as seen from Figure 9, prices converge when there are cost reductions within the LNG sector. We also see that cost reductions in the distance-related shipping segment provide the largest price convergence. This is an expected result, as LNG is the only transport option for N-A imports, and N-A is located most far away from the export market. On the other hand, reductions in pipeline cost lead to price divergence instead of convergence, in line with the theoretical reasoning in Section 2.



**Figure 10: Transatlantic trade per year to the N-A market (Mtoe)**



We would also expect the price differentials to be reflected in volumes of inter-regional trade. This is shown in Figure 10, displaying transatlantic trade volumes in each model scenario. The figure demonstrates that trade across the Atlantic Ocean to North America increases relative to the reference case when LNG costs fall. The largest effects on overseas trade volumes occur when the costs of the distance-related shipping segment are reduced. This is consistent with the price convergence observed in Figure 9. Conversely, if pipeline costs are reduced, we see that transatlantic trade drops considerably before it ultimately rises again at the end of the model horizon. This is largely explained by increasing LNG exports from Latin America to N-A, until reserves in Latin America gradually are depleted and overseas trade volumes replace the supply from this region.

Finally, the increased transatlantic gas trade due to LNG cost reductions also induces higher import dependence of natural gas in North America. Likewise, reduced pipeline costs will induce larger import dependence of natural gas in Western Europe. For politicians concerned with security of (gas) supply, this may be seen as a negative side effect from transport cost reductions.

## 5. Conclusion

In this study we have investigated how reduced costs within the transport segment of natural gas may affect prices and trade patterns. For trade between two regions, reduced transport costs will generally lead to lower prices in the import region and higher prices in the export region. We find that this conclusion has to be relaxed if more than two regions are involved in trade. Within a three-node model framework with one export region, we show theoretically that the importing region with the shortest distance to the export market may experience *higher* prices when transport costs fall. Likewise, if there are two export regions, the exporter with the shortest distance to the import market may have its

prices *reduced*. Although this study focuses on the natural gas markets, the results may also be relevant for other industries with bilateral trade between regions.

Using a comprehensive numerical model of the international gas markets, with 13 regions integrated through bilateral trade, we largely recognise the theoretical findings when we simulate the effects of transport cost reductions. Reduced costs within the LNG transport segment consistently lead to reduced producer prices and increased gas exports to the North American market. Due to the relative proximity to the LNG export regions and a dominance of pipeline imports, prices in Western Europe generally increase in this case. However, as North America is a pure LNG importing region, reduced pipeline costs will generally lead to increased prices in North America, and lower prices and increased imports to Europe. As North America has the highest original price level, this means that transatlantic prices will converge when LNG costs fall and diverge when pipeline costs fall.

Our results are particularly thought-provoking for European gas consumers in the sense that much attention has been paid to cost reductions for the LNG technology, followed by increased globalization of the regional gas markets. In such a scenario regional gas prices will converge. However, Europe will most likely experience relatively higher natural gas prices from LNG cost reductions, unless shipping costs are dramatically reduced. These results are quite robust even in a situation where all pipeline options from the Middle East are cut off. Hence, the best setting for transport related price reductions in Europe seems to be technology improvements for pipeline transport. For North America, on the other hand, further cost reductions in the LNG chain, especially shipping costs, will be beneficial for its gas consumers.

## References

- Asche, F., P. Osmundsen and R. Tveterås (2002): European market integration for gas? Volume flexibility and political risk, *Energy Economics* **24**, 249-265.
- Aune, F.R., S. Glomsrød, L. Lindholt and K.E. Rosendahl (2005): Are high oil prices profitable for OPEC in the long run? Discussion Papers No. 416, Statistics Norway, Oslo.
- Boots, M.G., F.A.M. Rijkers and B.F. Hobbs (2004): Trading in Downstream European Gas Market: A Successive Oligopoly, *The Energy Journal* **25** (3), 73-102.
- BP (2007): *BP Statistical Review of World Energy 2007*.
- Brito, D.L. and P.R. Hartley (2007): Expectations and the Evolving World Gas Market, *The Energy Journal* **28** (1), 1–24.
- Brooke, A., D. Kendrick, A. Meeraus and R. Raman (1998): *GAMS – A Users Guide*. Gams Development Corporation, Washington, DC.
- Cornot-Gandolphe, S. (2005): LNG cost reductions and flexibility in LNG trade add to security of gas supply, *Energy Prices and Taxes* 1<sup>st</sup> Quarter 2005, 29-36.
- Cremer, H., F. Gasmi and J.-J. Laffont (2003): Access to Pipelines in Competitive Gas Markets, *Journal of Regulatory Economics* **24**, 5-33.
- Cremer, H. and J.-J. Laffont (2002): Competition in gas markets, *European Economic Review* **46**, 928-935.
- Egging, R.G. and S.A. Gabriel (2006): Examining market power in the European natural gas market, *Energy Policy* **34**, 2762-2778.
- EIA (Energy Information Administration) (2003): The Global Liquefied Natural Gas Market: Status and Outlook. <http://www.eia.doe.gov/oiaf/analysispaper/global/index.html>
- EIA (Energy Information Administration) (2004): LNG industry costs declining. <http://www.eia.doe.gov/oiaf/analysispaper/global/lngindustry.html>
- EMF (Energy Modeling Forum) (2007): *Prices and Trade in a Globalizing Natural Gas Market*. EMF report 23, Stanford University, July 2007. <http://www.stanford.edu/group/EMF/projects/emf23/emf23.pdf>.
- EU (1998): directive 98/30/EC (the gas directive). [http://eur-lex.europa.eu/LexUriServ/site/en/oj/1998/l\\_204/l\\_20419980721en00010012.pdf](http://eur-lex.europa.eu/LexUriServ/site/en/oj/1998/l_204/l_20419980721en00010012.pdf)
- EU (2003): directive 2003/55/EC (the second gas directive). [http://eur-lex.europa.eu/LexUriServ/site/en/oj/2003/l\\_176/l\\_17620030715en00570078.pdf](http://eur-lex.europa.eu/LexUriServ/site/en/oj/2003/l_176/l_17620030715en00570078.pdf)
- Gabriel, S.A., S. Vikas and D.M. Ribar (2000): Measuring the influence of Canadian carbon stabilization programs on natural gas exports to the United States via a 'bottom-up' intertemporal spatial price equilibrium model, *Energy Economics* **22**, 497-525.
- Gabriel, S. A., J. Zhuang and S. Kiet (2005): A large-scale linear complementarity model of the North American natural gas market, *Energy Economics* **27**, 639-665.

- Golombek, R., E. Gjelsvik and K.E. Rosendahl (1995): Effects of Liberalising the Natural Gas Markets in Western Europe, *The Energy Journal* **16** (1), 85–111.
- Golombek, R., E. Gjelsvik and K.E. Rosendahl (1998): Increased Competition on the Supply Side of the Western European Natural Gas Market, *The Energy Journal* **19** (3), 1–18.
- Greaker, M. and E. Sagen (2004): Explaining experience curves for LNG liquefaction costs: Competition matter more than learning, Discussion Papers No. 393, Statistics Norway, Oslo.
- Hagen, K.P., H.J. Kind and J.G. Sannarnes (2004): Network Ownership and Optimal Tariffs for Natural Gas Transport, Working Paper No. 48/04, Institute for Research in Economics and Business Administration, Bergen.
- Hirschhausen, C. von, B. Meinhart and F. Pavel (2005): Transporting Russian Gas to Western Europe: A Simulation Approach, *The Energy Journal* **26** (2), 49-68.
- IEA (2006): *Natural Gas Market Review 2006. Towards a Global Gas Market*, Paris: OECD/IEA 2006.
- IEA (2007): *Natural Gas Market Review 2007. Security in a globalising market to 2015*, Paris: OECD/IEA 2007
- Jensen Associates (2007): The Outlook for Global Trade in Liquefied Natural Gas - Projections to the year 2020, Report prepared for California Energy Commission, August 2007.
- Jensen, J.T. (2003): The LNG Revolution, *The Energy Journal* **24** (2), 1–46.
- Jensen, J.T. (2004): *The Development of a Global LNG Market. Is it Likely? If so When?* NG 5, Oxford Institute for Energy Studies, Oxford.
- Kleit, A. (1998): Did Open Access Integrate Natural Gas Markets? An Arbitrage Cost Approach, *Journal of Regulatory Economics* **14**, 19-33.
- Liu, G. (2004): Estimating Energy Demand Elasticities for OECD Countries. A Dynamic Panel Data Approach, Discussion Papers No. 373, Statistics Norway, Oslo.
- MacAvoy, P.W. and N.V. Moshkin (2000): The new trend in the long-term price of natural gas, *Resource and Energy Economics* **22**, 315-338.
- Marmer, V., D. Shapiro and P. MacAvoy (2007): Bottlenecks in regional markets for natural gas transmission services, *Energy Economics* **29**, 37-45.
- Micola, A.P. and D.W. Bunn (2007): Two markets and a weak link, *Energy Economics* **29**, 79-93.
- Mizuno, K. and T. Shinkai (2006): Delegating Infrastructure Projects with Open Access, *Journal of Economics* **88**, 243-261.
- Newbery, D. (1999): *Privatization, Restructuring, and Regulation of Network Utilities*, London, UK and Cambridge, US: The MIT Press.
- OME (2001): Assessment of Internal and External Gas Supply Options for the EU, Evaluations of the Supply Costs of New Natural Gas Supply Projects to the EU and an Investigation of Related Financial Requirements and Tools, Observatoire Méditerranéen de l'Energie.

- Robinson, T. (2007): Have European gas prices converged? *Energy Policy* **35**, 2347-2351.
- Sagen, E. L. (2007): The LNG shipbuilding market – will costs continue to fall?, forthcoming Discussion paper, Statistics Norway.
- Sagen, E. and M. Tsygankova (2006): Russian Natural Gas Exports to Europe. Effects of Russian Gas Market Reforms and the Rising Market Power of Gazprom, Discussion Papers No. 445, Statistics Norway, Oslo (forthcoming in *Energy Policy*).
- Serletis, A. and J. Herbert (1999): The message in North American energy prices, *Energy Economics* **21**, 471– 483.
- Siliverstovs, B., G. L'Hegaret, A. Neumann and C. von Hirschhausen (2005): International market integration for natural gas? A cointegration analysis of prices in Europe, North America and Japan, *Energy Economics* **27**, 603-615.
- USGS (U.S. Geological Survey) (2000): *World Petroleum Assessment 2000*.
- Zhao, J. (2000): Diffusion, Costs and Learning in the Development of International Gas Transmission Lines, IIASA Interim Report IR-00-054, Laxenburg.