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Implementation of the Hogan, Rosellón, and Vogelsang (HRV) incentive mechanism into the InTraGas model*

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Abstract

The European natural gas market is characterised by higher demand than available supply from own resources. Therefore Europe is a gas net-importing region. The costs of potential problems or disruptions establish the need for an environment which stimulates sufficient investments in transmission line capacities. We examine the effects of the introduction of the recently developed Hogan, Rosellón and Vogelsang (HRV) incentive mechanism into the European natural gas market. In the simulations with GAMS we can confirm all results expected from theory. The validity of these simulation results is confirmed in a structural analysis, which comprised the variation of different exogenous input parameters. Therefore we conclude that the HRV incentive mechanism as a regulatory regime for the European natural gas market would be an advisable alternative, which should be considered in future discussions.

1 Introduction

The combined European region is a net importer of natural gas, due to insufficient own resources. Although some single countries like the Netherlands or the UK are net exporting countries, the aggregated demand in Europe as a whole depends on imports from foreign regions. With respect to that, the most important gas exporting countries for the European Union are Russia, North Sea and Algeria. Potential dangers of such an import dependency became obvious in the 2008/2009 dispute, when Russia interrupted gas flows transiting the Ukraine. This peaked in a disruption of 300-350 million cubic meters (mcm) per day and meant that all in all 5 bcm of transit gas supply were not delivered over a two week period characterised by very low temperatures, which even worsened the situation (IEA (2009)).
Beside the dangers arising from contractual disagreements and resulting supply disruptions, additional problems emerge if demand grows faster than the necessary investments in transmission expansion take place. These circumstances are resulting in congestions of transmission capacity. Referring to the International Energy Agency (IEA), investments in transmission expansion to avoid congestions are necessary for Europe in order to cope with the challenges of rising demand on a medium to long term level, combined with falling output in many producing countries. Uncertainties concerning the market conditions and the regulatory environment reduce the willingness of investors to finance the necessary expansions. Therefore, it is important for Europe to agree on a regulatory basis, which on the one hand sets sufficient incentives for the transmission companies to invest in pipeline capacities and on the other hand acts as an anchor for a stable regulatory environment.

Several theoretical models are available, as one important part of regulatory theory traditionally deals with natural monopolies, where due to high fixed costs and technological efficiency a single operating firm is most advantageous. Well known examples for natural monopolies are markets depending on a network, like the telecommunication, electricity, water and gas industry. While competition can for example arise between single suppliers of natural gas, the transportation via pipelines constitutes a natural monopoly. Therefore, it has to be regulated in order to protect market participants from abuse of market power by the network-operating monopolist.[1] Due to the characteristics of the European natural gas market described above, a regulatory approach for Europe should set sufficient incentives for transmission companies to invest in transmission expansion, especially in congested areas. One theoretical approach, intended to set such incentives, is the recently developed Hogan, Rosellón, and Vogelsang incentive mechanism (Hogan et al. (2010)). Consequently, this paper tries to examine the effects of introducing the HRV incentive mechanism, explicitly taking into account the characteristics of the European natural gas market.

The remaining paper is structured as follows. Section 2 provides a literature overview, with focus on gas market models and different regulatory approaches. Section 3 continues with the model description. This consists of two parts the InTraGas model, which constitutes the basis of our analysis, and the integration of the HRV incentive mechanism by extending the model to a two stage optimisation problem. The complete model was implemented and solved in GAMS[2], the 4th section presents simulation results and the findings of a structural analysis. Finally, the last section summarises our main findings and draws together the principal conclusion.

[1] See Train (1991) and Armstrong et al. (1994)
[2] General Algebraic Modelling System.

2 Literature Review and placement of the current work

Several models for natural gas markets are available in literature, each of them dealing with different aspects of the market conditions and interactions. One example is GASMOD, a Strategic Model of European Gas Supply, described in Holz et al. (2008). This model is structured as a two–stage game and captures the interaction between successive natural gas exports to Europe (upstream market) and wholesale trade within Europe (downstream market). Herein, it explicitly includes infrastructure capacities. Moreover the World Gas Model, developed by Egging et al. (2009), has to be mentioned. This model is a multi-period mixed complementarity model for the global natural gas market up to the year 2040 and captures 98% of the world gas market production and consumption.
Our work tries to contribute ideas to the application of models concerning transmission investments. We want to concentrate on models of the European gas market, which include transmission of natural gas. According to Neumann et al. (2009), three different approaches for natural gas transportation models can be distinguished, namely the system dynamic approach, linear optimisation problems and the use of complementarity models. Neumann et al. provide a model for *Investments into Transmission Facilities of Natural Gas (InTraGas)*, which is implemented as non-linear optimisation problem. Within this model, the authors identify existing transportation bottlenecks and examine the impact of transmission expansion on market conditions and total welfare. As this model refers to the European natural gas market and focuses on investments in transmission capacities, it perfectly meets our requirements. Therefore, we choose this model as basis for the implementation of a regulatory mechanism. Furthermore the InTraGas model is explicitly designed for the purpose of a regulatory model approach.

Referring to the regulatory framework, several incentive schemes are available. The traditional regulatory paradigm for natural monopolies, like the transmission grid of natural gas, is rate-of-return regulation, which refers to constraining the rate of return on invested capital. Despite its popularity and its advantages in easy application, this approach includes some disadvantages, like the Averch–Johnson effect of overcapitalisation (Averch and Johnson (1962)) or the missing of cost–reducing incentives for the monopolist. Therefore, continuative models concentrate on incentive schemes, a principal agent framework and pricing decisions of the firms. When deviating from the first best solution of marginal costs pricing, Ramsey–Boiteaux pricing, which sets prices inversely proportional to price elasticities, would for instance generate second best results in the sense of welfare maximising prices under the condition of commercial viability.[3] Nevertheless, Ramsey–Boiteaux pricing is not popular, due to its enormous information input requirements. The most common incentive scheme is RPI-X regulation dating back to Littlechild (1983). It refers to price or revenue caps, which set investment incentives through a division of prices and costs.[4] The predetermined price development, which is corrected for inflation (i often measured by the retail price index RPI) and efficiency aims (X), allows for extra profits from cost reducing investments. Herein, Vogelsang (2001) developed a very interesting approach presented in Equation (1). His price cap mechanism incorporates a two–part tariff splitting the price into a variable and a fixed charge, as often used in electricity and gas markets. Within this framework efficient investment incentives should arise from the rebalancing of variable and fixed charges. Efficient investment will lower the variable charge and consequently allow for an increase in the fixed charge, which in turn finances the investment. The variable charge (p) is multiplied by the produced amount (q) and the fixed charge (F) by the number of users (N).[5]

[3] See for example Borrmann and Finsinger (1999) or Train (1991).
[4] See for instance Joskow (2005), Armstrong et al. (1994) and Jamison (2007).
[5] Weights (w) are needed for produced amount as well as number of users, usually last year values are used ($q^w = q_{t-1}$ and $F^w = F_{t-1}$) which is called Chained Laspeyres weights.

$$(p_t q^w + F_t N^w) \leq (p_{t-1} q^w + F_{t-1} N^w)(1 + i - X) \tag{1}$$

One recently developed comprehensive model is the Hogan, Rosellón, and Vogelsang incentive mechanism (Hogan et al. (2010)). This framework combines the advantages of regulatory and merchant[6] models for investments into transmission capacities. In particular the HRV incentive mechanism combines a Vogelsang (2001) regulatory constraint as described above and merchant elements, like long–term financial transmission rights (LTFTR), which are especially important for electricity markets in order to handle loop–flows and to guarantee variable charges representing congestion rents. For gas markets the explicit usage of LTFTR can be replaced by actual gas transports, because variable charges can be determined as difference between single nodal prices to represent congestion rents.

The framework comprises two stages. First, there is an upper problem concerning the profit maximisation of the Transmission Company (TransCo), which faces the Vogelsang (2001) regulatory constraint. The two decision variables of a TransCo operating in gas markets are capacity and fixed fee. Second, the lower level problem refers to the welfare maximisation of an independent system operator (ISO), constraint by market characteristics. The ISO matches supply and demand and thereby determines variable charges as difference between nodal prices.

Within the HRV incentive mechanism the sequence of decisions is important. First the TransCo decides on installed capacities, these capacities enter welfare–maximisation considerations of the ISO, which in turn determines supply and demand to compute variable charges. Given variable charges, the TransCo sets the fixed charge by rebalancing the regulatory constraint. In that concern, the stages are closely linked and incentives for transmission expansion should arise. Due to this comprehensive and well–conceived design, the HRV incentive mechanism seems to meet the requirements of the European natural gas market and it is interesting to examine the potential effects of its adaption.

The adequacy of theoretical models, in achieving predetermined aims, always has to be examined for real markets. A reasonable way of testing the effects of applying a specific theoretical model is to calibrate a simulation model with real market data. With this procedure, it is possible to compare the current market situation with market conditions arising after the introduction of the theoretical model. Many regulatory models concerning transmission expansion have been tested in such a way. For example Ramírez and Rosellón (2002) proceeded in this way to examine the effects of the Vogelsang (2001) model when introducing it to the Mexican natural gas industry. Brito and Rosellón (2009) used a similar approach for the analysis of the incentives arising from a two–part tariff model in a fictive market using reasonable parameters. The effects of the introduction of the HRV mechanism were also examined in an application for the electricity sector. Rosellón and Weigt (2011), implemented the HRV mechanism in a simulation model for the electricity market in Belgium, the Netherlands and Luxembourg, including its connections to France and Germany. The authors find a significant increase in transmission capacity, a convergence in prices on the marginal generation level and an overall convergence to the welfare optimum. Further research of the authors yielded similar results for the separate electricity markets in the PJM region, Canada and Mexico.

Our paper integrates the HRV mechanism in a simulation model for the European natural gas market and in that extends the sequence of applied projects of this incentive scheme. The movement from the electricity market to other industries is especially interesting in order to get insights whether the HRV mechanism works for different markets. Therefore, we explicitly account for characteristics of the European natural gas market and treat the strong dependency of foreign imports. Within our application,

[6] Herein allocations and auctions of necessary investments are handled by an ISO. The merchants (various economic agents) could invest in new transmission capacity and finance their investments through the sale of long–term financial transmission rights.

the InTraGas model is used for the representation of the European natural gas market, as suggested and intended by its creators. We find that the introduction of the HRV regulation into this model generates extensions in congested areas, with increasing fixed charges and decreasing variable charges, therefore leading to an overall increase in total welfare. In that, our findings confirm the results expected from theory and resemble the results for the electricity sector. Nevertheless, in contrast to Rosellón and Weigt (2011) we find an increase in consumer surplus.

3 Model formulation and data

The methodical approach is to employ the InTraGas model which is already implemented in GAMS, to introduce the HRV incentive mechanism in this framework and to analyse resulting changes in welfare. Consequently, the entire model is coded in GAMS accounting for the characteristics of the European natural gas market and the HRV incentive mechanism. Both elements are explained in the following subsections.

3.1 InTraGas Model

The underlying model of the European natural gas market is a simplified version of the InTraGas[7] model developed by Neumann et al. (2009) at the Chair of Energy Economics and Public Sector Management (EE2) at Dresden University of Technology. It represents the existing European natural gas network, including major Non-European exporting regions. For simplification, the number of regions is reduced in this paper to basically four importing regions with high demand and low domestic gas production (Belgium and the Netherlands, France, Germany, and Italy), and three exporting regions with high production capacities (North Sea, Russia, and North Africa). The natural gas network in the model is a stylised representation of the existing gas pipeline system aggregating all facilities within one region into one node. Cross border connections between countries are summed up within one pipeline connecting the respective nodes. Consequently, natural gas can only be transported via the European pipeline system, and the conversion to liquefied natural gas (LNG) and corresponding transportation by van and ship is not considered in this paper.

Reference data in the InTraGas model is calibrated to represent 2005 values and is provided on a monthly basis covering a representative year. Maximum production data ($g_t^{\max}$) are taken from IEA (2006) and BP (2006). For non-exporting countries indigenous production is defined as maximum production capacity. Production costs are taken from OME (2005). To define a linear demand function, reference demand is taken from IEA (2006) and BP (2006), a reference price of 2.75 €/MBtu, and a price elasticity of demand[8] of -0.3 at this point is defined. Natural gas pipeline capacities between the nodes of the model are gathered from Gas Infrastructure Europe GIE (2005) and transformed into mcm per year. Transportation costs for pipeline transmissions are derived from OME (2005) and transposed into a transport price per km and transported volume.

Using these input data, the InTraGas model determines welfare optimal production and demand of natural gas ($g_{n,t}$ and $d_{n,t}$) in region n and period t as well as the flow between single nodes ($flow_{n,nn,t}$) according to Equation (2). Herein, welfare is defined as gross consumer surplus assuming a linear demand function ($p(d_{n,t})$) minus production costs ($c_n g_{n,t}$) and transportation costs. Costs of producing natural gas are country specific (c_n) and transportation costs depend on the transportation distance between nodes n and nn. Moreover welfare optimisation is subject to the Energy Balance as market clearing

[7] InTraGas stands for investments into transmission facilities of natural gas.

[8] The value goes for instance in line with estimated price elasticities from Filippini (1999) for the Swiss electricity market and Lampietti and Meyer (2003) for different heating sectors.

condition and two technical constraints. Production and pipeline transportation capacity cannot exceed the maximum available capacity (Production Capacity and Pipeline Capacity). The Energy Balance is used to determine the price for natural gas in each node. The price for transmission of natural gas, namely the variable charge, is subsequently calculated by the difference between nodal prices, thereby representing congestion rents. The optimal production schedule is determined in an annual basis and therefore monthly dynamics of the natural gas markets are neglected.

$$\max_{g_{n,t},d_{n,t},flow_{n,nn,t}} W = \sum_{n,t}\left[\int_0^d p(d_{n,t})dd_{n,t} - c_n g_{n,t} - \sum_{nn} tcr \cdot distance_{n,nn} flow_{n,nn,t}\right] \tag{2}$$

$$d_{n,t} + \sum_{nn} flow_{n,nn,t} \leq g_{n,t} + \sum_{nn} flow_{nn,n,t} \quad \forall n, nn, t \tag{Energy Balance}$$

$$0 \leq g_{n,t} \leq g_n^{\max} \quad \forall n, t \tag{Production Capacity}$$

$$0 \leq flow_{n,nn,t} \leq flow_{n,nn}^{\max} \quad \forall n, nn, t \tag{Pipeline Capacity}$$

The described welfare maximisation problem from the InTraGas model will represent the welfare maximisation problem of an independent system operator in the HRV incentive mechanism framework.

3.2 Model formulation with HRV incentive mechanism

To incorporate the Hogan, Rosellón, and Vogelsang (HRV) incentive mechanism[9], the welfare maximisation problem of an independent system operator (ISO) and the profit maximisation problem of the transmission company (TransCo) have to be connected. Therefore, the basic model needs to be extended by the profit maximisation of the transmission company. It is assumed, that the TransCo is the investing party and is responsible for investing in network infrastructure on a European level.

Equation (3) defines the profit of the TransCo as revenues, consisting of congestion revenues, expressed by $(p_{nn,t} - p_{n,t})flow_{n,nn,t}$, and the fixed charge of the regulatory constraint (F_t), minus transportation costs ($\sum_{nn} tcr \cdot distance_{n,nn} flow_{n,nn,t}$) and investment costs ($\sum_{n,nn} extension_{n,nn,t} I$) depending on the capacity added to the existing pipeline system. The decision variables of the TransCo are the investment decision ($extension_{n,nn,t}$) and the fixed charge of the regulatory constraint (F_t).

Additionally, the profit maximisation of the TransCo is subject to a Vogelsang (2001) type of regulatory constraint, a price cap mechanism on two–part tariffs with a systematically responsive fixed fee on variable charges. This constraint ensures, that the revenues in period t are lower or at least equal to period $t-1$, adjusted for inflation, measured by the retail price index (RPI), and efficiency improvements (X). In that way, it is ensured that the TransCo can set prices in a best–capacity–utilising way and finance necessary investments in pipeline capacity. Herein, efficient expansion investments will increase the transportation volume and reduce prices in the natural gas market. However, a reduction in prices also cuts off the profits of the TransCo, namely the congestion rent. This loss in revenues can be rebalanced by increasing the fixed charge (F_t) of the regulatory constraint. In that, incentives for efficient expansion investments are given.

[9]As described in Hogan et al. (2010), section *6.2.3 Formulation for a capacity–setting TransCo.*

$$\max_{extension_{n,nn},F_t} \quad \pi = \sum_t \frac{1}{1.1^{t-1}} \begin{bmatrix} (p_{nn,t} - p_{n,t}) flow_{n,nn,t} \\ -\sum_{nn} tcr \cdot distance_{n,nn} flow_{n,nn,t} \\ +F_t - \sum_{n,nn} extension_{n,nn,t} I \end{bmatrix} \tag{3}$$

$$\frac{\sum_n (p_{n,t} d_{n,t} - p_{n,t} g_{n,t}) + F_t}{\sum_n (p_{n,t-1} d_{n,t} - p_{n,t-1} g_{n,t}) + F_{t-1}} \leq 1 + RPI - X \quad \forall t \qquad \text{(Regulatory Constraint)}$$

Both optimisation problems have to be closely linked in the HRV incentive mechanism. The profit maximisation of the TransCo (Equation (3) and Regulatory Constraint) represents the upper problem, whereas the welfare maximisation problem of the ISO (Equation (2), Energy Balance, Production Capacity and Pipeline Capacity) gives the lower problem. Consequently the TransCo moves first and decides on investments ($extension_{n,nn,t}$).[10] The investments in network capacity enter the Pipeline Capacity constraint of the lower problem and affect market results namely the variable charges and the quantities. Nodal prices ($p_{n,t}$), generation ($g_{n,t}$) and demand quantities ($d_{n,t}$), and transportation volumes ($flow_{n,nn,t}$) are determined. Finally, given the variable charges of the lower problem the TrasnsCo rebalances the regulatory constraint to define the fixed charge (F_t).
The entire model is coded in GAMS as a dynamic mathematical programme with equilibrium constraints (MPEC), therefore allowing for connected upper and lower optimisation problems. The lower problem is reformulated as a mixed complementarity problem (MCP) and first of all solved once in order to act as an anchor for the optimisation of the TransCo. Developments over 15 periods are simulated subsequently.

4 Results

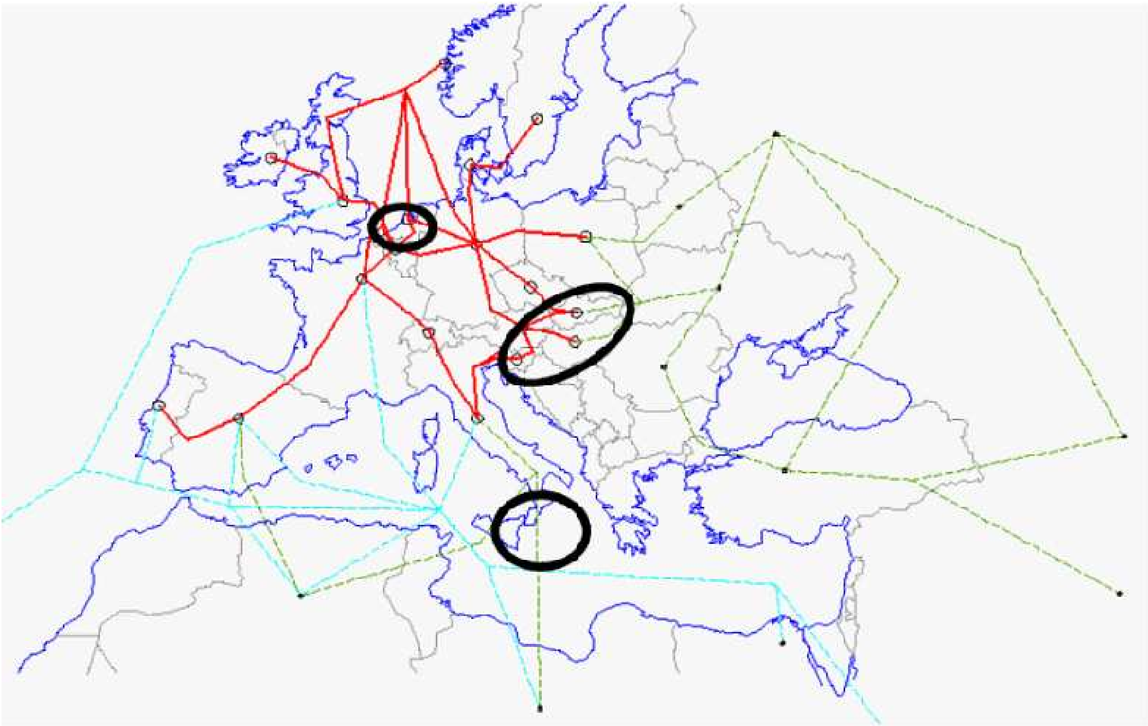
As described in the last section, we implemented the Hogan, Rosellón, Vogelsang incentive mechanism as an MPEC problem and solved it in GAMS. The obtained results over 15 simulation periods are presented in this section. We start with an examination of the effects of introducing the HRV regulation by using a reference scenario. These effects are further evaluated in a structural analysis with respect to different input parameters. In the structural analysis we compare the development of welfare, extensions and return on investment of the transmission company (TransCo) in each scenario.

4.1 Impacts of the HRV incentive mechanism

The analysis of the European gas market using the simplified InTraGas model presented above, is taken as initial situation and thus acts as base case for evaluating the introduction of HRV regulation. From theory, the expected impacts of introducing the HRV incentive mechanism should be extensions in congested transmission capacities, an increase in fixed charges and a convergence in variable charges of considered regions. These changes should altogether lead to an increase in total welfare.
The initial examination with the InTraGas model showed congestion of transmission appears in three major areas. Figure 1 presents a simplification of the transmission net for natural gas in Europe, the congested areas are highlighted with black circles. As expected, congestions take place between France and the Benelux states, Italy and Africa as well as between Eastern Europe and Russia.

[10]For this decision the TransCo needs an anchor for variable charges, which has to be determined from the lower problem.

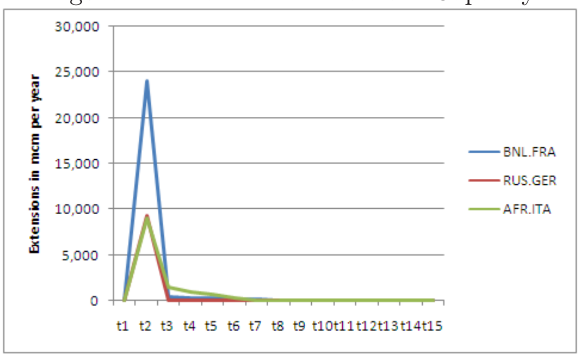
Figure 1: Congested Transmission Lines in Europe



Source: Neumann et al. (2009)

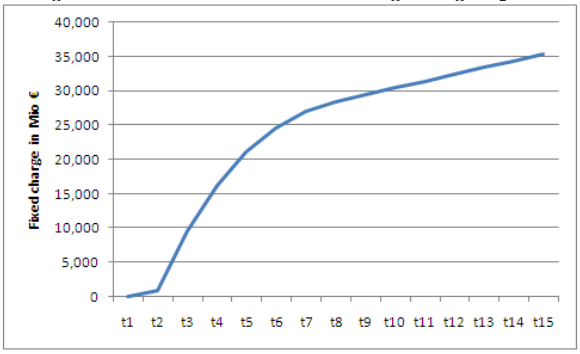
Congested transmission lines cause reasonable costs for consumers and introduce a high degree of uncertainty. Brito and Rosellón (2009) for example found in empirical evaluations that consumers are even more willing to pay the costs of transmission expansion than to bear the costs of congested lines and potential resulting outages. In line with this, one most important and desired effect of the HRV incentive mechanism is to set incentives for transmission expansion.
Figure 2 presents the extensions arising in our simulations, when introducing the HRV incentive mechanism. As can be seen in the graph, the main investment period within the 15 years is the second period. Moreover, transmission expansion exactly takes place in the formerly congested areas of the natural gas network in Europe. The biggest investments are carried out between France and the Benelux states, while the investments in transmission capacities between Germany and Russia as well as Africa and Italy behave very similar. This confirms the theoretical assumption that the HRV mechanism only sets incentives for necessary transmission expansion projects, and triggers a fast realisation of these necessary projects.

Figure 2: Extensions in Network Capacity



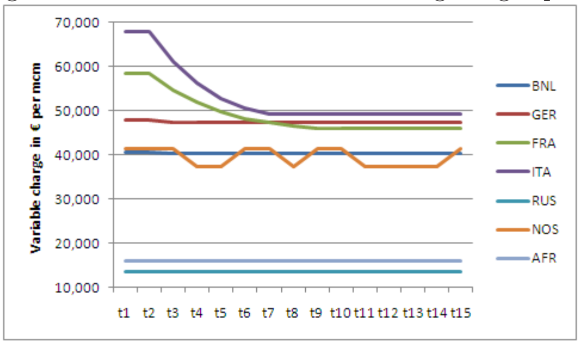
Within the framework of the HRV incentive mechanism, consumers are offered a two–part tariff, which should ensure optimal allocation, due to marginal cost pricing concerning the variable charge, and non-negative profits for the transmission company, due to the possibility to set a fixed charge according to their investment decisions. This constitutes one incentive for transmission companies to invest in transmission expansion, because they do not face the danger of future losses, but are rather compensated by consumer payments. Figure 3 presents the fixed charge[11] development after introducing the HRV incentive mechanism. In consistency with extensions presented above, the fixed charge starts to rise from the second period on and is thus able to compensate the transmission company for investments.

Figure 3: Increase in fixed charge of gas price



In order to guarantee optimal allocation, the variable charge should equal marginal costs. A clear convergence of variable charges in the different regions should therefore be apparent. Figure 4 shows the resulting development of variable charges in our simulations, when the HRV incentive mechanism is implemented. From the second period on, a downward trend of variable charges in the net-importing regions can be seen, which starts right after the period when extensions were undertaken. As the variable charges in the net exporting regions, Russia and Africa, do not increase it is not a convergence towards each other, but rather a convergence of all variable charges to the costs of gas.[12] Therefore, the economy as whole is approaching a state of optimal allocation.

Figure 4: Decrease in the variable charge of gas price



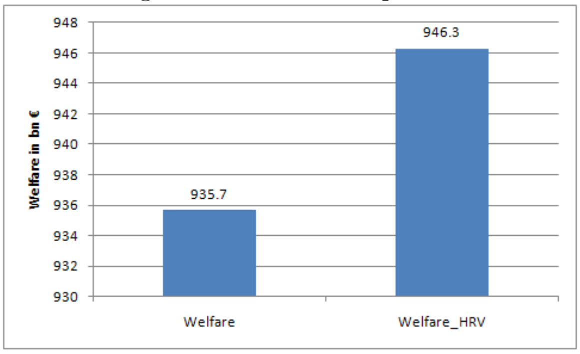
The described effects of introducing the HRV incentive mechanism into the InTraGas model of the European natural gas market result in an overall increase in total welfare of about 1%, as shown in Figure 5. This result is very similar to the one obtained by Rosellón and Weigt (2011), who found an overall increase of welfare of about 1.7%. Nevertheless, it should be noted that presented welfare effects only refer to the 15 periods simulated and thus rather constitute a lower bound of the total welfare

[11] Recall that within the framework of a two–part tariff, the price is split into a variable charge and a fixed charge.

[12] The costs of gas comprise the marginal costs of gas plus the transportation costs and are represented via the variable charges in Russia and Africa.

effects. Welfare is measured as the total amount of consumer and producer[13] surplus. In the European natural gas market, consumer surplus under HRV regulation accounts for the bigger part in welfare and constitutes around 96%, whereas Rosellón and Weigt (2011) reported a decrease in consumer surplus when introducing the HRV mechanism in the electricity market.

Figure 5: Welfare Comparison



Summarising the main findings in this section, introducing the HRV incentive mechanism in our simulations exactly yields the results assumed and predicted from theory. Extensions in congested transmission capacities take place, fixed charges increase and variable charges show a convergence to marginal costs of cheap production, which in summary leads to an increase in total welfare. Therefore, theoretically expected results from the HRV mechanism are not exclusively valid for the electricity sector but also hold for the European natural gas market.

4.2 Structural analysis

In order to check robustness of the obtained results and to get further confirmation, this paper conducts a structural analysis concerning the introduction of the HRV incentive mechanism into the European natural gas market. Several exogenous input parameters are varied, to examine the sensibility of the effects of introducing the HRV incentive mechanism on exogenous conditions. The price elasticity of demand (ε) is varied between -0.01 and -1.50, the reference price scenarios reach from 50,000 to 150,000€ per mcm, the transportation cost ratio (TCR) is modified between 0.5 and 20, and finally an increase in production costs in Africa and Russia to the European level is simulated. The different situations, arising from the varied exogenous parameters, are compared by means of aggregated grid extensions in 15 periods, TransCo's return on investment and resulting welfare, separated in consumer and producer welfare, as well as welfare surplus (from HRV scenario in comparison to the InTraGas model) over 15 periods.

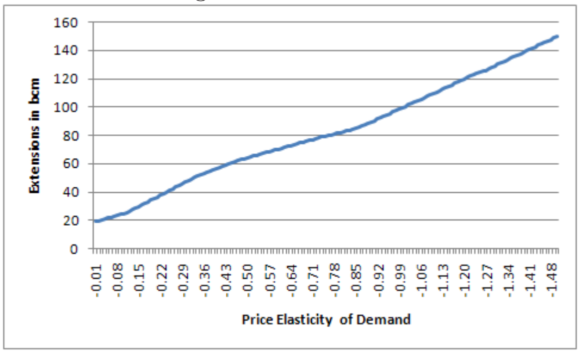
4.2.1 Price Elasticity of Demand

Typically, the price elasticity of demand for wholesalers is assumed to be around -0.3 in empirical studies. Filippini (1999) estimated for example a price elasticity of demand of -0.3 for wholesalers in Swiss electricity markets. Additionally, a study from NIEIR (2004) which estimated the price elasticities of a variety of Australian consumer groups arrives at a price elasticity of -0.35 for commercial consumers. Last but not least, Neumann et al. (2009) also assumed a price elasticity of demand around -0.3 for calibrating the InTraGas model to the European natural gas market. Beside these, several other empirical studies deal with the estimation of certain price elasticities. Bohi (1981) for example mentions that short–run elasticity for aggregate electricity varies between -0.03 and 0.54. Concerning the case of long–term elasticities,

[13] Note that producer always refers to the transmission company, in the sense of producer of the network.

he found values ranging from -0.45 to -2.1.
In order to cope with the range of estimated price elasticities of demand and to monitor the sensitivity of the model, we allow price elasticity of demand to vary between -0.01 and -1.50. Figure 6 shows the resulting development of transmission expansion[14] under HRV regulation, when changing price elasticity of demand from -0.01 to -1.50. In order to achieve comparability, the aggregated extensions over all 15 periods are presented for each price elasticity of demand. A clear positive correlation between the price elasticity of demand and cumulated extensions is illustrated. The higher the absolute value of price elasticity is, the higher are cumulated extensions over 15 periods. This is intuitive due to the meaning of price elasticity. Negative price elasticities of demand demonstrate that demand decreases when prices increase. The higher this negative price elasticity is in absolute values, the more distinct are demand responses on price changes. Therefore, increased price elasticity triggers more and more gas imports from the cheapest region, namely Russia. In the simulations, cumulated extensions are concentrated on pipelines from Russia to Germany with increasing price elasticity and due to the necessity of distributing the gas in Europe, extensions from Germany to other European countries also increase.

Figure 6: Extensions



Due to investments in grid extension, it is possible for transmission companies to set a positive fixed charge, which in turn affects their profits positively. Thus the profit of the TransCo also increases in absolute values. Nevertheless, the relation of profits to transmission expansion investments measured by the return on investments (ROI) decreases with an increase in the absolute value of price elasticity of demand, as presented in Figure 7. This shows once again that consumers profit from a high price elasticity of demand.

Figure 7: Return on Investment of the TransCo

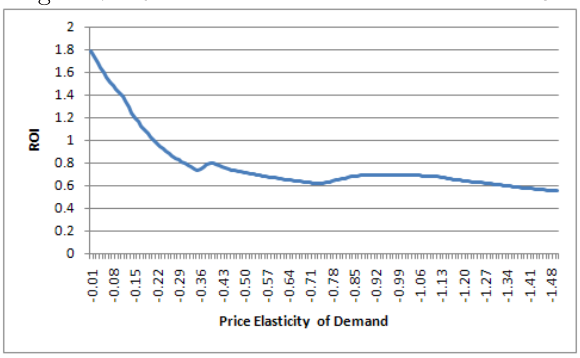


Figure 8 finally presents welfare development, arising from variation of the price elasticity of demand. Welfare, measured over 15 periods, in the HRV regulation setup is split in consumer and producer welfare

[14]Transmission expansion refers to investing in grid extensions.

and represented via the red and blue area, respectively. Additionally, the green line illustrates welfare over 15 periods arising from the InTraGas model. An increase in consumer surplus would be expected when increasing price elasticity of demand in absolute values, as indicated in the last paragraph. Indeed a massive reduction of consumer surplus is observable. This is due to the linear demand function. Both, the intersection and the slope of the linear demand function depend on the price elasticity of demand. If price elasticity of demand is close to zero, the linear demand function becomes nearly vertical and hence the area below the demand function increases significantly. Summing up, the overall development of welfare is mainly caused by the linear definition of demand function and should not be taken too seriously. Nevertheless, what remains convincing is a welfare comparison between the HRV regulation and the InTraGas base case scenario. Figure 9 shows that the more price–elastic demand is, the higher is the welfare surplus gained by introducing the HRV regulation in comparison to the InTraGas model.[15]

Figure 8: Welfare

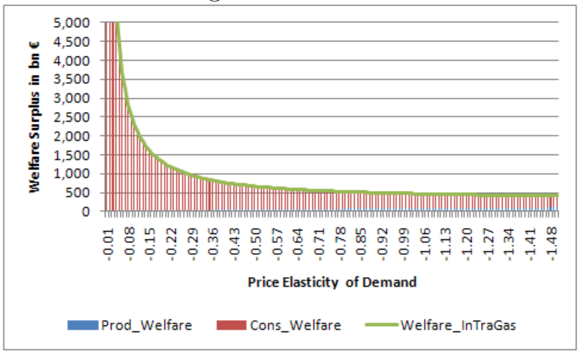
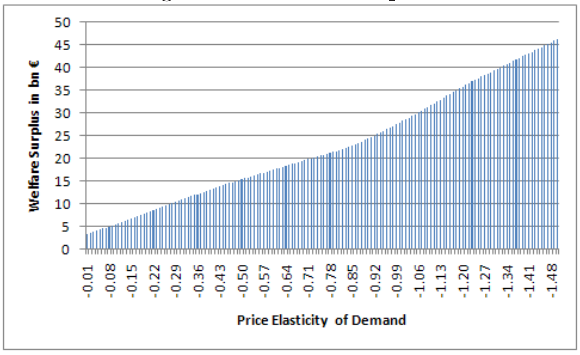


Figure 9: Welfare Surplus



4.2.2 Reference Price

Incremental increases in the reference price from 50,000 to 150,000€ per mcm trigger an increase in extensions. This could have been anticipated because a higher level of the reference price increases necessity of and incentives for transmission expansion to areas with cheaper gas. Due to the increase in extensions the profit of the transmission company rises, which can be attributed to the possible positive fixed charge aligned to extensions. Nevertheless, the return on investments shows a rather negative correlation with the reference price.[16]

The overall changes due to an increase in the reference price lead to an increase in producer as well as consumer welfare. But similar to price elasticity, a change of the reference price affects intersection and slope of the linear demand function. Therefore, overall welfare development is mainly driven by the characteristics of linear demand. Consequently, it is again advisable to concentrate on a welfare comparison between HRV regulation and the InTraGas model. Figure 11 shows that the higher the reference price is, the higher is the obtained welfare surplus from introducing the HRV incentive mechanism. This appears intuitive, as transmission expansion incentives from HRV regulation translate via increased extensions into lower variable charges, which increases consumer welfare in comparison to the InTraGas base case.

[15] Note that welfare surplus is measured as cumulated 15–periods welfare of HRV regulation (red plus blue bar) subtracted by the 15–periods welfare in the InTraGas model (green line). Therefore positive values indicate an increase in welfare from HRV regulation in comparison to the actual gas market situation represented by the InTraGas model.

[16] Figures 25 and 26 in the appendix provide the development of extensions and ROI, respectively.

Figure 10: Welfare

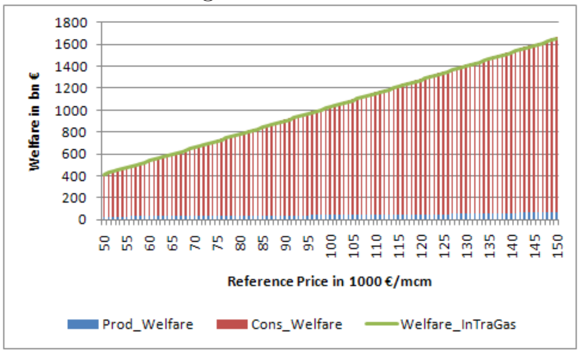
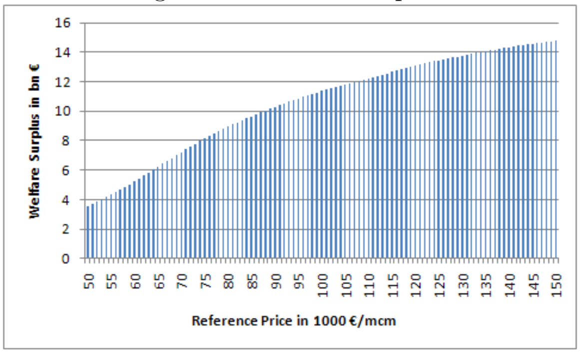


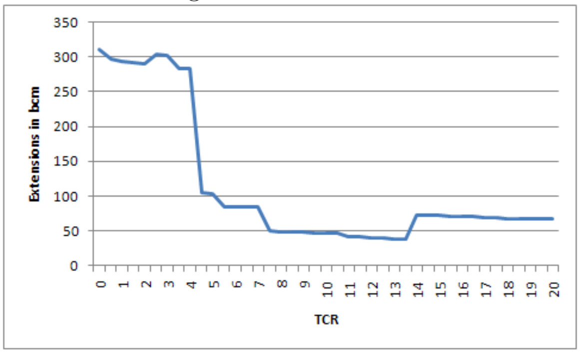
Figure 11: Welfare Surplus



4.2.3 Transportation Cost Ratio (TCR)

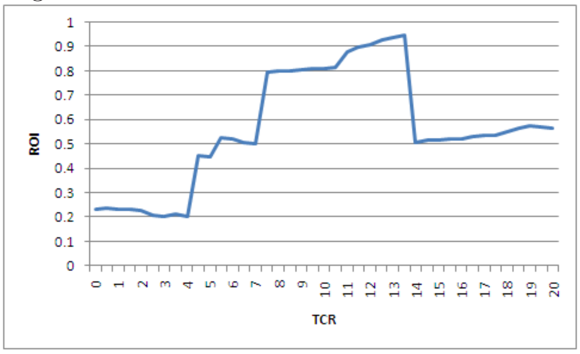
Recall that the transportation costs for pipeline transmission are derived from OME (2005) and transposed into a transport price per km and transported volume. Figure 12 presents the development of extensions for incremental increases in the transportation cost ratio from 0.5 to 20. As expected a rather negative correlation between aggregated extensions and the transportation cost ratio becomes visual, with the highest decrease between a transportation cost ratio of 3 and 5. Rather surprisingly appears the slight increase in extensions when the transportation cost ratio rises from 13 to 15. One toehold might be that from a specific level on, transportation costs are already so high, that total costs have to be reduced via cheaper gas production.

Figure 12: Extensions



The development of the TransCo's profit proceeds quite similar to the extensions – altogether a rather negative correlation between profit and transportation cost ratio, interrupted by a slight increase for higher transmission cost ratios. This can be attributed to the undertaken extensions and the resulting fixed charge increase. As profits and extensions again behave similar in absolute values, their mutual relation is interesting. Therefore, Figure 13 presents the return on investment when increasing the transportation cost ratio from 0.5 to 20. Below TCR values of 13, the ROI and the TCR yield a rather positive correlation, indicating that extensions decrease slightly more than profits. Nevertheless, the increase in extensions between a transportation cost ratio of 13 and 14 seems to outweigh the increase in profits and the ROI decreases.

Figure 13: Return on Investment of the TransCo



The above described developments result in a slight decrease of total welfare under HRV regulation, which is shown in Figure 14. The overall decrease in the first part of the graphic is driven by a welfare loss of producers, whereas the decrease in the second part is dominated from losses in consumer welfare. Welfare in the InTraGas model is also decreasing with an increasing transportation cost ratio, represented via the green line. Nevertheless, welfare surplus of introducing the HRV incentive mechanism, assessed in comparison to the InTraGas base case scenario, is still always positive as demonstrated in Figure 15. Variation of the TCR underlines the connection between extensions and welfare, as the developments are quite consistent – higher extensions are accompanied by lower welfare surplus. In line with this, especially for low and high values of TCR, welfare surplus is distinct.

Figure 14: Welfare

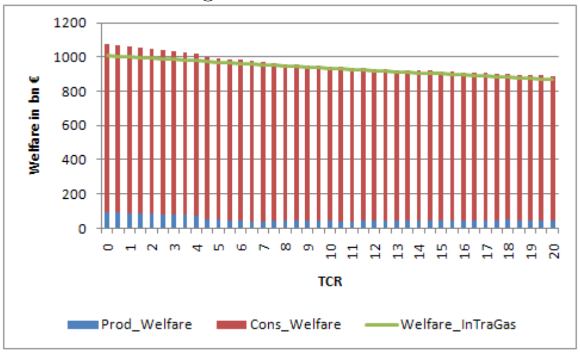
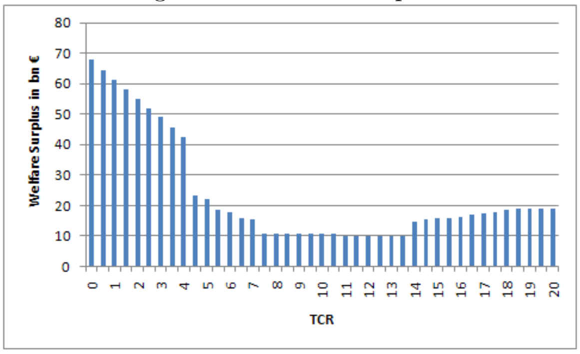


Figure 15: Welfare Surplus



4.2.4 Production Costs

Due to the strong dependency on foreign production possibilities, another interesting question with respect to the European natural gas market refers to the potential consequences of an increase of production costs in the most important supplier regions, Africa and Russia. Intuitively, one would expect that extensions into these regions are declining, when the difference in production costs diminishes. The overall welfare effects can be ambiguous, due to the fact, that consumer surplus might decrease, while producer surplus also has potential to increase. In addition to TransCo's welfare, its profit development faces some uncertainty. The profit might also increase or decrease, depending on which effect exceeds, an increase in production costs or the resulting increase in prices. Consequently, the development of return on investment is also vague.

1. **Russia**

   First, we present the results of an increase in the production costs in Russia from 5,000 to 41,000€. Figure 16 shows that this leads to a successive increase in extensions. Although this result conflicts with our ex ante expectations, it becomes reasonable if we consider the initial state of transmission capacities. The total transmission capacity of gas, measured at standard temperature and pressure, between Russia and Europe accounts for 123.52 bcm per year, whereas transmission capacity between Africa and Europe only reaches a level of 37.93 bcm per year. Therefore it is quite intuitively, that extensions are rather low for cheap Russian production costs, as the already existing capacities are used. But it becomes necessary and advantageous for the transmission company to invest in transmission lines to Africa in order to use the cheap gas production in this area, when the production costs in Russia increase over a specific level. The first distinct increase in extensions takes place when Russian production costs exceed African production costs, which are around 16,000€ per mcm. The next step is observable for Russian production costs between 34,000 and 35,000€ per mcm, which is around twice the African production costs. Both leaps are due to increased investments in transmission capacity from Africa to Europe.

Next, Figure 17 presents the change in return on investment triggered by an increase in production costs in Russia. Here an overall negative correlation can be observed. Although TransCo's profit is always positive, it never reaches the amount of investments in transmission expansion (because ROI is always below one) and its relative fraction decreases with increasing Russian production costs. Finally, extensions and welfare surplus, of introducing the HRV incentive mechanism in comparison to the InTraGas model, are again highly connected. Extensions once more translate into higher welfare surplus.

Figure 16: Extensions

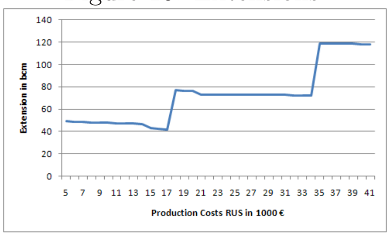


Figure 17: Return on Investment

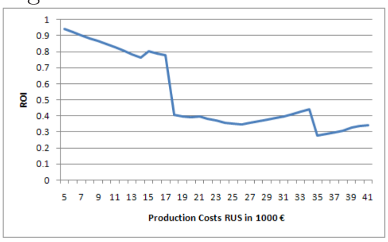
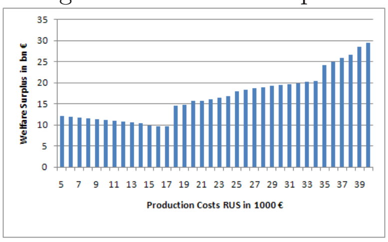


Figure 18: Welfare Surplus



2. **Africa**

We continue with results for an increase in production costs in Africa. Here the picture reverses. Figure 19 shows that the higher production costs in Africa are, the lower the accumulated extensions. This meets our ex ante expectations and can be explained by the already existing import capacities from Russia. For low production costs in Africa it is profitable for the TransCo to invest in transmission capacities from Africa to Europe. But the higher African production costs get, the more imports are shifted to already existing transmission capacities from Russia to Europe and consequently the less extensions are needed. As extensions are shrinking, the increase in production costs in Africa simply leads to a decrease in the return on investment of the transmission company, which is demonstrated in Figure 20. Finally these developments result in a slight decrease in total welfare surplus when introducing the HRV incentive mechanism, shown in Figure 21.

Figure 19: Extensions

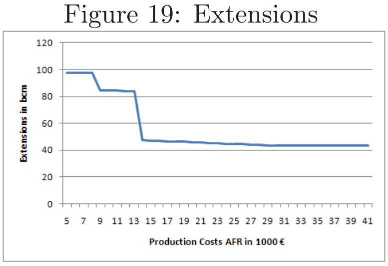


Figure 20: Return on Investment

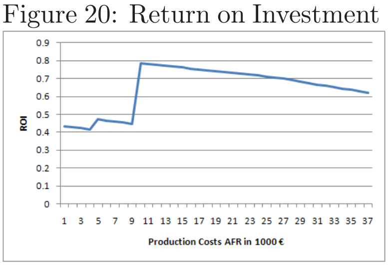
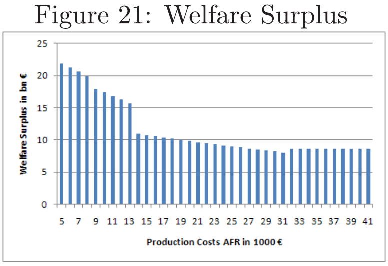


Figure 21: Welfare Surplus



3. **Africa and Russia**

   To conclude the structural analysis, the results of introducing the HRV incentive mechanism with a simultaneous increase in the production costs of Russia and Africa are presented. Not surprisingly, the results in this section somehow display the summarised results of a separate increase in production costs of Africa or Russia. Figure 22 shows a rather negative correlation with extensions; except for the recognisable increase when production costs are already close to the European level. Here it becomes advantageous for the transmission company to invest in further transmission capacities to Africa, as the existing ones to Russia are no longer sufficient for maximising profits. Accordingly, the return on investment of the transmission company also exhibits a rather decreasing development in Figure 23. Finally, Figure 24 once again highlights the close connection between extensions and welfare surplus by rather similar behaviour. Welfare surplus and extensions are decreasing with increasing production costs in Africa and Russia, except for production costs close to the European level where extensions to Africa take place.

Figure 22: Extensions

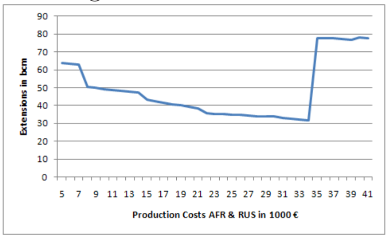


Figure 23: Return on Investment

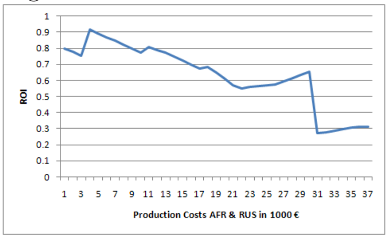
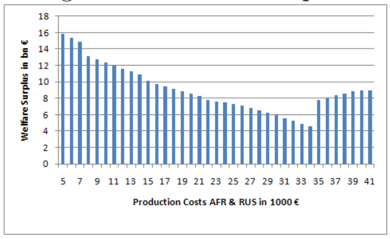


Figure 24: Welfare Surplus



5 Summary and Conclusion

The European natural gas market is characterised by higher demand than available supply from own resources, that is why Europe is a gas net–importing region. The costs of potential problems or disruptions, arising from contractual disagreements or congested transmission lines, establish the need for an environment which stimulates sufficient investments in transmission line capacities to regions with rich gas reservoirs. Uncertainties concerning the market conditions and the regulatory environment reduce the willingness of investors to finance these necessary expansions. Therefore, it is important for Europe to agree on a regulatory basis, which on the one hand sets sufficient incentives for the transmission companies to invest in pipeline capacities and on the other hand acts as an anchor for a stable regulatory environment.

The recently developed Hogan, Rosellón, and Vogelsang incentive mechanism implements a Vogelsang (2001) type of price cap mechanism and connects the profit maximisation problem of the transmission company to the welfare maximisation of an independent system operator. In that, it is designed to set incentives for the transmission companies to invest in necessary transmission expansion. Therefore, introduction of HRV regulation into a network–based market, like the European natural gas market, should in theory cause transmission expansion in congested areas, an increase in fixed charges, a convergence of variable charges and altogether result in an increase in total welfare. Rosellón and Weigt (2011) already confirmed these theoretical results in an application of the HRV mechanism to an European electricity market.
We expand the InTraGas model of Neumann et al. (2009) to an MPEC in order to simulate the introduction of the HRV incentive mechanism into the European natural gas market. In our simulations are able to confirm all theoretical results of introducing the HRV mechanism for the European natural gas

market. The TransCo invests in transmission capacities between Russia and Germany, the Benelux states and France as well as between Africa and Italy, namely the areas in Europe with potential congestion in transmission lines. Consequently, an increase in the fixed charge as well as a convergence of variable charges can be observed. Thus introducing HRV regulation finally results in an increase in total welfare. The simulation results were validated in a structural analysis. In spite of varying different exogenous input parameters, like price elasticity of demand, reference price, transportation costs ratio or production costs, introducing the HRV incentive mechanisms always yields an increase in extensions and welfare, compared to the InTraGas model.

From the obtained simulation results we conclude that the introduction of the HRV incentive mechanism as regulatory regime for the European natural gas market, would generate positive welfare effects and improve market conditions. Additionally, the establishment of a stable regulatory environment would itself stimulate investments via higher security in market conditions. Nevertheless, every change of system or existing framework conditions is accompanied by switching costs, and introducing HRV regulation would require adaptations. But Directive 2009/73/EC seems to establish a promising basis. For example, member states of the European Union should disestablish vertical integration and implement ownership unbundling, an independent system operator or an independent transmission operator not later than 3rd of March 2012. All three possibilities guarantee an independent operation of gas transmission. So what really would be left to implement for Europe is a Vogelsang (2001) type of price cap regulation, which could be introduced in line with the creation of the European Agency for the Cooperation of Energy Regulators (ACER). Summing up, the HRV incentive mechanism seems to be an advisable alternative for the European system and its further consideration and investigation under different market conditions is highly interesting.

6 Appendix

Figure 25: Extensions

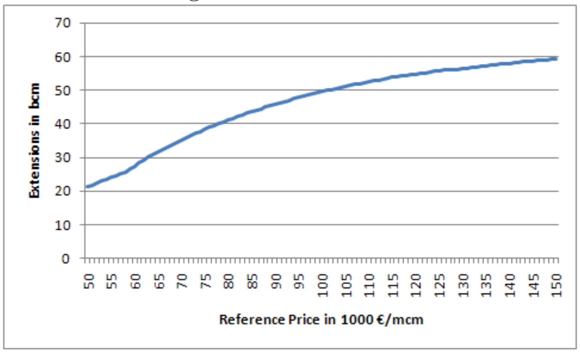
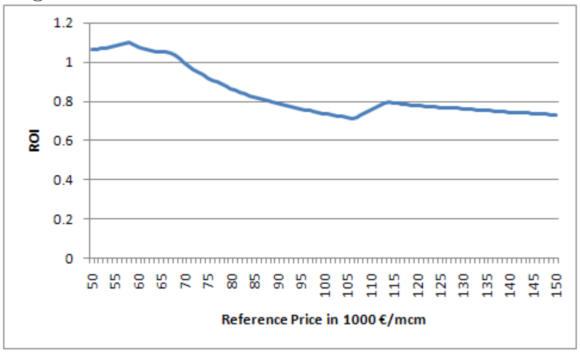


Figure 26: Return on Investment of the TransCo



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