A Top-Down Approach to Evaluating Cross-Border Natural Gas Infrastructure Projects in Europe

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Abstract

There is an ongoing policy debate in Europe about how to select natural gas infrastructure projects for an EU-wide investment support scheme. We contribute to this debate by providing a model-based project evaluation method that addresses several shortcomings of the current approach, and by demonstrating its use on a set of shortlisted investment proposals in Central and South Eastern Europe. Importantly, our selection mechanism deals with the complementarity and the substitutability of new pipelines. We find that a few projects are sufficient to maximize the net gain in regional welfare, but different baseline assumptions favor different project combinations. We also explore the consequences of Russian gas being permanently delivered at the border of the EU on northern and southern routes that avoid Ukraine, and find modest negative welfare effects.

1 Introduction

Cross-border investments in electricity and natural gas transmission networks raise unusual challenges for cost-benefit analysis. Trading on a new interconnector narrows price differences across markets, making consumers better off on one side, but worse off on the other. Producer surplus moves in the opposite direction, while storages (in case of gas) can either gain or lose profits, depending on seasonal demand-supply patterns. Market participants in directly and indirectly connected third countries are also affected. Moreover, the new infrastructure element might only be needed in case of a serious (but rare) supply disruption. These complications can prevent the neighboring transmission system operators (TSOs) and governments from investing into projects that would otherwise be beneficial for the larger region.

Europe, with over 30 interconnected national electricity and gas markets, is a prime area for contrasting bilateral and regional approaches to cross-border transmission investment. Aware of the threat of underinvestment in market interconnection, the European Union (EU) established a system for supporting energy infrastructure projects deemed essential for a fully integrated European market and for security of supply. These projects

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of common interest (PCIs) may benefit from accelerated planning, permitting and environmental process, and they can access financial support provided by the EU.[1] There is, however, no clear consensus about how PCIs should be chosen and evaluated.

In this paper, we contribute to the policy debate by providing a model-based project evaluation method for the natural gas sector, and by demonstrating its use on a set of currently shortlisted PCIs in Central and South Eastern Europe (CSEE). Our main tool is the European Gas Market Model (EGMM), a competitive short-run equilibrium model for the natural gas market in Europe.[2]

The currently used method to identify projects for PCI status has been developed by the European Network of Transmission System Operators for Gas (ENTSOG). It has been tested in two PCI selection rounds (in 2013 and 2015), and is subject to continuous fine tuning (ENTSO-G [2013]). Frontier Economics [2014] and ACER [2014] have, however, pointed out shortcomings of the ENTSOG methodology by—among others—(1) not providing impact estimates on stakeholders other than consumers and producers; (2) not breaking down benefits by EU member states; (3) not including non-EU members; (4) falling short on identifying complementary and competing projects; and (5) oversimplifying on transportation costs. The market-based evaluation method we propose in this paper deals with all of the above issues.

Our project evaluation mechanism proceeds in three steps. First, we establish baseline scenarios taking into account expected demand, supply, and long-term contractual positions, as well as infrastructure elements (pipelines, storages, LNG terminals) that are likely to be operational by 2020 (our year of analysis). The model we use is detailed enough to provide equilibrium surplus estimates for all market participants in each EU and non-EU country we include. Second, we simulate market outcomes by adding all possible combinations of shortlisted PCIs to the baseline case. Third, we compare the increase in regional welfare for each pipeline combination against the joint investment costs, and provide a ranking of project *sets* based on our annual net social benefit measure. By considering every feasible PCI configuration, rather than single projects in a selected order, our ranking method allows for an endogenous determination of which projects are competing and which ones are complementary.

Our main result is an illustrative set of proposed PCIs under each baseline scenario. Even though the analysis presented in this paper is not exhaustive, we can still draw some general lessons from our exercise. All baseline scenarios suggest that the central region of South Eastern Europe (roughly around the core of Serbia) is most in need of pipeline investments. In the reference case, connecting Serbia and Greece through Bulgaria (southern supply direction) brings the highest net benefits for the region. The construction of a long-planned LNG terminal on the coast of Croatia would, however, make it more beneficial to build pipelines from Croatia to Serbia and to Hungary (western supply direction).

Regardless of which baseline we look at, it is never optimal to build all the proposed projects. The southern and western directions are clearly competing in the model, but we also see evidence of strong complementarity: the Bulgaria-Serbia pipeline is only worth

[1]The first list of PCIs was published in 2013, which was reduced to a number of short and mid-term key infrastructure projects in the Communication of the Commission on its Energy Security Strategy (European Commission [2014]). See the European Commission's portal at https://ec.europa.eu/energy/en/topics/infrastructure/projects-common-interest for more details.

[2]The EGMM has been developed at the Regional Centre for Energy Policy Research (REKK). It was previously used to evaluate Projects for Energy Community Interest in South Eastern Europe (KEMA and REKK [2013]), and to address supply security questions (Sartor et al [2014]).

building in the reference case if it is accompanied by the Greece-Bulgaria interconnector. In an actual project evaluation, it is therefore important to choose a representative set of baseline scenarios and to pay careful attention to properly weighing them.

Somewhat contrary to our expectations, we also find that the direct welfare gains of pipeline investor countries tend to be on the level of the CSEE region as a whole, and sometimes even larger (making third countries minor net losers from the investment). Partly, this result reflects the limited number of scenarios we consider, but it also raises questions about the exact mechanism through which the PCI scheme improves welfare for the EU itself.[3]

As a secondary application, we also demonstrate the advantages of the EGMM's treatment of long-term supply contracts in conjunction with the proposed PCI evaluation mechanism. We explore a hypothetical baseline scenario in which the contract delivery points of gas arriving from Russia are moved to the country where the gas enters the EU, and all transit routes from the east avoid crossing the territory of Ukraine.[4] Although this is a large shift from the current mode of operation, we find that its negative welfare consequences for the CSEE region are modest. However, this result depends crucially on our assumption about a (not-yet-existing) southern route becoming available for carrying Russian gas.[5] The new baseline reorders the ranking of project combinations as well, putting a north-to-south supply direction from Poland at the top of the list. Implementing the proposed PCIs has the potential to neutralize around 30 percent of the welfare decrease in the region. We also discuss other potential benefits, such as the improvement of buyer bargaining position, after presenting our results.

1.1 Literature

Our paper fits into an extensive literature on the numerical equilibrium modeling of natural gas markets. Prominent modeling tools and applications focusing on the European consumer market include GASTALE (Boots et al [2004], Egging and Gabriel [2006]), NATGAS (Zwart and Mulder [2006], Zwart [2009]), TIGER (Lochner and Bothe [2007], Lochner [2011], Dieckhöner et al [2013]), GASMOD (Holz et al [2008]), the World Gas Model (Egging et al [2010]), the Global Gas Model (Holz et al [2013], Richter and Holz [2015]), GaMMES (Abada et al [2013]), and the EPRG-Gas Market Model (Chyong and Hobbs [2014]). Smeers [2008] provides an in-depth discussion of the models existing before 2010. Here we only concentrate on the defining differences of our approach from the main stream of efforts.

Most models (except for TIGER) allow for strategic behavior by upstream firms, and in some cases, also in the downstream market. Our approach is different. We assume that all market participants are price takers.[6] Working with the perfectly competitive equi-

[3] We calculate our welfare measure as an unweighted sum of surpluses, whereas national governments might assign unequal weights to different stakeholders. In theory, favoring certain groups (consumers, for example) can decrease the willingness to build a pipeline that harms those groups, but brings net benefits overall.

[4] The original role of long-term gas purchase contacts and the underlying fundamentals are described by Neuhoff and Hirschhausen [2005], Asche et al [2002], Stern and Rogers [2014] and Henderson and Pirani [2014].

[5] Hence our intention is not to model a supply disruption scenario, but rather a permanent shift to alternative delivery routes and destinations. Richter and Holz [2015] carry out simulations for disruptions to transits through Ukraine without assuming a new southern route, and find substantially more severe effects for a similar set of countries as we do.

[6] Storage and transmission system operators have exogenously given fees that exceed marginal costs.

librium has its drawbacks: the presence of market power is an important issue, at least in the upstream market. We remedy this shortcoming by including a detailed representation of long-term take-or-pay contracts in the model. Our assumption is that most of the upstream market power exercise happens through the pricing of these contracts, and the market works more like the competitive benchmark in the short run. Accordingly, a single simulation run of our model encompasses one calendar year.[7]

The price-taking assumption allows us to go into finer detail both geographically and in the temporal dimension. We aggregate demand to the country level, but not across countries. The modeling literature often lumps small neighboring markets (e.g. in South Eastern Europe) together for computational convenience, which rules out the analysis of interconnection between these markets. We also break the modeled time frame down to monthly periods, whereas the cited models typically include only 1-3 seasons per year. The monthly detail is especially helpful when looking at market disturbance scenarios, as these tend to be short-living, and the extent to which storage units can mitigate them depends on short-run gas withdrawal capacities. In terms of geographical and temporal granularity, our model is close to—but still less detailed than—the TIGER model.[8] However, we do allow for price responsive demand functions and can therefore carry out a more informative welfare analysis. The inclusion of a rich take-or-pay contracting structure in the EGMM also lets us examine the effect of virtual reverse flows on integrating markets with limited physical connectivity.

We use a comparative static framework for our project evaluations, contrasting equilibrium outcomes with and without the investments, which could—in theory—be also carried out with other cited models that are sufficiently detailed. Some models even go beyond the static approach and allow for infrastructure changes within the time frame of the simulations. Lise and Hobbs [2008] extend the GASTALE model to automatically include new pipelines and storage units whenever the forecasted congestion rents exceed a specified threshold value.[9] In the Global Gas Model, transmission and storage system operators decide about new investments based on a private cost-benefit analysis.

Endogenizing the investments of profit-oriented, but geographically limited entities in interconnected markets is not straightforward. It is not clear, for example, how the substitutability or complementarity of new pipelines can be modeled if the investment decisions are taken project-by-project by non-overlapping (or partially overlapping) sets of TSOs. In reality, policy makers with their own objectives also need to consent to the investments, which complicates a profit-based cost-benefit analysis.[10] Finally, even the parties to a single pipeline can have diverging dynamic incentives, which leads to complex bargaining problems and potentially to wasteful spending.[11] Using the comparative statics approach, we have to make assumptions about what infrastructure will be available in the future, in exchange for a more transparent analysis that avoids the shortcomings

[7]As a result, we have nothing to say about the price development of long-term supply contracts. Models with a strategic upstream sector do address producer price setting, although they tend to abstract away from the take-or-pay clauses. For a richer endogenous contracting model, see Abada et al [2014].

[8]See Dieckhöner [2010] for a supply security application exploiting the granularity of TIGER.

[9]For further applications, see Lise and Hobbs [2009] and Lise et al [2008].

[10]Joskow and Tirole [2005] and Brunekreeft et al [2005] describe similar tensions between the social benefits and the private profitability of “merchant” investment in electricity transmission capacity.

[11]Hubert and Suleymanova [2008] examine extensions to the Eurasian gas transmission network through a dynamic bargaining model, and conclude that the absence of international contract enforcement results in inefficient investments relative to the cooperative outcome (the default assumption in an endogenous cost-benefit analysis).

of endogenous investment models. Since we focus on a relatively short time frame, we find this trade-off acceptable.

2 Model

The EGMM is a competitive, dynamic, multi-market equilibrium model for natural gas production, trade, storage, and consumption in Europe. It explicitly includes a supply-demand representation of 33 European countries,[12] as well as their gas storages and transportation links to each other and to the outside world (mainly to large LNG and pipeline gas exporters). The time frame of the model is 12 consecutive months, starting in April. Market participants have perfect foresight over this period.

2.1 Market participants

There are four kinds of players within the model: consumers, local producers, importers, and traders. Consumers in each market within the region are represented by a linear monthly gas demand function that only depends on the contemporaneous local wholesale price of gas. For outside markets, we use perfectly elastic demand functions at exogenously given prices.

Local producers have piecewise linear short-run cost functions, with upper and lower limits on monthly production and a separate upper constraint on yearly output.

Importers own long-term take-or-pay (TOP) contracts that are sourced from gas exporters in outside markets, most importantly from Russia, Norway, Algeria, and a number of LNG exporting countries. Each contract specifies a price, a delivery route, and a minimum and maximum delivered quantity per month and per year. The monthly minimum delivery constraint alone is flexible: it can be violated, but most of the undelivered gas must be paid for according to the TOP rules.

The function of traders is to move gas between markets using cross-border pipelines and LNG shipments, and between time periods using storages.

2.2 Infrastructure

2.2.1 Transportation

Transportation links between two markets consist of cross-border pipelines and LNG routes. From a modeling perspective, they operate similarly. Each link is unidirectional[13] and has a maximum transportation capacity. Pipelines have entry and exit tariffs, and LNG connections have shipping costs, regasification prices, and network injection fees.

Transportation infrastructure can be used for delivering gas into the target market through long-term contracts or spot trade, and into the source market via virtual reverse flow ("backhaul"). Virtual reverse flow can only be carried out if there is already a pre-contracted gas flow in the default direction.[14] Even then, its availability may be limited by the legal environment, which is captured as an additional constraint in the model.

[12] 26 member states of the European Union (all except for Cyprus and Malta) and the following non-members: Albania, Bosnia and Herzegovina, Macedonia, Moldova, Serbia, Switzerland, Ukraine.

[13] Any number of links between two markets are possible in each direction.

[14] Because of take-or-pay obligations, gas sometimes flows from high-priced to low-priced markets. Even if there is no physical connection in the reverse direction, the price difference can be profitably exploited by backhaul shipments.

Formally, physical flows on a piece of transportation infrastructure are given by:

$$x_f^s = t_f^s - b_f^s + \sum_c \Omega_{fc}^s \cdot (d_c^s + D_c^s) \tag{1}$$

where f indexes the infrastructure, s the time period (month), and c the long-term contracts. t_f^s is the amount of spot trade and b_f^s is the amount of backhaul shipment on infrastructure f. $d_c^s + D_c^s$ is the total delivered quantity on contract c, and Ω_{fc}^s specifies what portion (typically 0 or 1) of contract c flows through infrastructure f in month s.

We also include in the model upper constraints on linear combinations of physical flows to separately account for the regasification capacity of LNG terminals and the total shipment capacity of LNG exporters.[15]

2.2.2 Storage

Storage units reside within 23 out of the 33 markets we explicitly model. Each has a monthly injection and withdrawal capacity and associated fees. In addition, storages have a working gas capacity and exogenously given starting and year-end inventory levels. Traders can decide in each month how much gas they want to inject into, or withdraw from, a storage unit. Inventory levels can never fall below zero or rise above the working gas capacity of a facility. Storages must eventually be reloaded to the specified year-end inventory level (usually equal to the starting inventory).

2.3 Decision variables

Local producers decide about production levels (e_p^s), importers about the quantity of delivered gas up to (d_c^s) and above (D_c^s) the monthly TOP quantities, and traders about spot trade (t_f^s) and backhaul (b_f^s) on transportation infrastructure, and injection (i_g^s) to and withdrawal (w_g^s) from gas storages. (p indexes the producers and g the storages.) Although consumers are listed as participants in the model, their consumption is derived from the other decision variables as:

$$Q_m^s = \sum_p \Pi_{mp} \cdot e_p^s + \sum_f \Phi_{mf} \cdot x_f^s + \sum_g \Gamma_{mg} \cdot \left(w_g^s - i_g^s\right) \tag{2}$$

where m indexes markets, and Π_{mp} and Γ_{mg} are zero-one parameters indicating whether producer p and storage g are in market m. Φ_{mf} is also an indicator: it equals 1 if market m is the target of transportation infrastructure f, -1 if it is the source, and 0 otherwise.

2.4 Equilibrium

A crucial assumption in the EGMM is that producers, importers, and traders are all price-takers. In equilibrium, all arbitrage opportunities across time and space are therefore exhausted to the extent that storage facilities, transportation infrastructure, and contractual conditions permit. As a result, the competitive equilibrium yields an efficient outcome and can equivalently be computed as the solution to a constrained welfare

[15] These constraints allow for an endogenous determination of which LNG exporter will ship to which LNG terminal in equilibrium.

maximization problem with the following multi-period objective function:

$$\begin{aligned} W = \textstyle\sum_s \beta^s \Big\{ & \textstyle\sum_m \left[\int_0^{Q_m^s} P_m^s(Q)\, dQ\right] - \sum_p Ce_p^s \cdot e_p^s - \sum_g Ci_g^s \cdot i_g^s - \sum_g Cw_g^s \cdot w_g^s \\ & - \textstyle\sum_f Ct_f^s \cdot \left[\sum_c \Omega_{fc}^s \cdot (d_c^s + D_c^s) + t_f^s\right] - \sum_f Cb_f^s \cdot b_f^s - \sum_f Pt_f^s \cdot \left(t_f^s - b_f^s\right) \\ & - \textstyle\sum_c Pd_c^s \cdot d_c^s - \sum_c PD_c^s \cdot D_c^s \Big\} \end{aligned} \tag{3}$$

In the welfare expression, β is the month-to-month discount factor, $P_m^s(Q)$ is the (linear) inverse demand function in market m and period s, and the (quadratic, concave) integral term measures gross consumer surplus.

On the cost side, Ce_p^s is the marginal cost of local production. Ci_g^s and Cw_g^s denote the storage fees for injection and withdrawal. Ct_f^s is the transportation fee on infrastructure f for gas flows in the default direction, and Cb_f^s is the fee payable for virtual reverse flows. If infrastructure f originates (ends) in an outside market, then Pt_f^s is (-1 times) the exogenously given price in that market. $\sum_f Pt_f^s \cdot \left(t_f^s - b_f^s\right)$ therefore measures the total cost of net spot imports from outside markets. Finally, Pd_c^s and PD_c^s are the marginal prices of gas below and above the minimum monthly delivery limit of long-term contracts.[16]

The objective function is continuous and weakly concave with a non-empty, closed and convex domain, ensuring the existence of an equilibrium. With minor additional assumptions, the equilibrium also becomes a unique one.[17] We find it by solving the first-order linear complementarity conditions of the constrained optimization problem using standard pivoting techniques (Gabriel et al [2013]).[18]

2.5 Welfare

We use storage and transportation fees in our objective function (3) as if they were the marginal costs of these activities, even though the fees typically exceed the marginal costs to ensure a sufficient return on capital invested into the infrastructure. Similarly, using a low marginal price for the gas bought below the monthly delivery limit in a long-term contract does not reflect the full cost of the gas, because the take-or-pay obligation creates a large fixed cost element as well. Despite these qualifications, the welfare formulation in expression (3) is the one that allows us to replicate the competitive equilibrium.

In our *ex post* welfare calculations, we adjust the maximized value of our objective function to properly account for actual welfare in the market. We add the operating profit of transmission and storage system operators using estimates for their marginal costs, and increase the expenditure on import contracts by the take-or-pay fixed cost element. The augmented welfare used for evaluating the benefit of new infrastructure is

[16]Because of the financial penalties associated with take-or-pay obligations, Pd_c^s tends to be 70-90% lower than PD_c^s.

[17]Uniqueness might not hold, for example, if there are more than one unconstrained marginal producers in the same location. Since marginal production costs are assumed to be constant, any feasible distribution of the joint output across the equal-cost producers is part of an equilibrium outcome, even though all such equilibria lead to the same market price. This multiplicity is not an issue in practice, however.

[18]The full set of complementarity conditions are available in the online appendix.

therefore given by:

$$\begin{aligned}\hat{W} = W + \textstyle\sum_s \beta^s \Big\{ & \textstyle\sum_g \left(Ci_g^s - \hat{Ci}_g^s\right) \cdot i_g^s + \sum_g \left(Cw_g^s - \hat{Cw}_g^s\right) \cdot w_g^s \\ & + \textstyle\sum_f \left(Ct_f^s - \hat{Ct}_f^s\right) \cdot \left[\sum_c \Omega_{fc}^s \cdot (d_c^s + D_c^s) + t_f^s\right] + \sum_f \left(Cb_f^s - \hat{Cb}_f^s\right) \cdot b_f^s \\ & + \textstyle\sum_c \left(PD_c^s - Pd_c^s\right) \cdot Kd_c^s \Big\}\end{aligned} \tag{4}$$

where $\hat{Ci}_g^s$, $\hat{Cw}_g^s$, $\hat{Ct}_g^s$, and $\hat{Cb}_g^s$ are the (constant) marginal costs of storage injection, storage withdrawal, pipeline/LNG transportation in the default direction, and backhaul. Kd_c^s is the minimum monthly take-or-pay obligation, and $(PD_c^s - Pd_c^s) \cdot Kd_c^s$ is the monthly fixed cost component of a long-term contract. All numerical welfare values in the paper are the result of evaluating expression (4) at the competitive equilibrium with given input parameters.

We assign all welfare components to regional and outside markets based on location. For consumer and local producer surplus, long-term contract profit,[19] storage operating income and congestion rent, the assignment is straightforward. Pipeline operating income is shared in the ratio of entry and exit fees and pipeline congestion rent is shared equally by the neighboring markets. LNG-related welfare components are assigned to the market hosting the terminal.

3 Methodology

We evaluate the social benefit of new cross-border pipelines by running market simulations with and without the new infrastructure and comparing aggregate welfare in the two equilibria. All simulations are for the year 2020 using forecasted values for demand, indigenous production, and long-term contracts in place.[20] In our baseline ("before investment") scenarios, we include all existing infrastructure, as well as all current projects that already have final investment decisions and are planned to be commissioned before 2020.[21] Most important among these for our analysis is the Trans Adriatic and the Trans Anatolian Pipeline (TAP/TANAP) connecting Turkey with Italy through Greece and Albania.[22]

We use three baseline scenarios for our evaluations. The first one is a business-as-usual case (*Reference*) with no additional assumptions. The second baseline scenario explores the market consequences of Russian gas being delivered at the border of the EU on routes that avoid Ukraine (*No Ukraine transit*). Finally, we examine the effects of a new LNG terminal in Croatia on the usefulness of cross-border pipeline investments in the region (*Adria LNG*).

In each case, we proceed by adding to the baseline setup all possible combinations of cross-border pipelines, chosen from a shortlist of proposed projects of common interest in the North-South Gas Corridor in the CSEE region,[23] and comparing the changes in

[19]By long-term contract profit, we always mean the profit that the importer earns by selling the delivered gas into the local wholesale market. As we take the contract prices as given, the profit of the exporter (e.g. Gazprom) is outside of both of our model, and our welfare measure of interest.

[20]We assume that the long-term supply contracts expiring before 2020 are not renewed.

[21]Our main data source is the capacity maps and the 2015 edition of the Ten-Year Network Development Plan of the European Network of Transmission System Operators for Gas (ENTSO-G [2015]).

[22]Other infrastructure to be operational by 2020 include interconnectors between Slovakia and Hungary, France and Spain, and the LNG terminal in Poland.

[23]We have added another pipeline (Croatia-Serbia) to our analysis, because it features high on a similar

Table 1: Potential Pipeline Projects of Common Interest in the North-South Gas Corridor in Central and South Eastern Europe

From	**To**	**Short name**	**Capacity** (bcm/year)	**Length** (km)	**Diameter** (inch)	**Investment cost** (million €/year)
Bulgaria	Serbia	BG-RS	1.8	150	28	12.6
Croatia	Hungary	HR-HU	2.8	0/308	39	2.4/31.2†
Croatia	Serbia	HR-RS	6.0	102	31	9.4
Greece	Bulgaria	GR-BG	3.0	185	32	15.0
Poland	Czech Rep.	PL-CZ	5.0	108	39	12.5
Poland	Slovakia	PL-SK	5.4	164	39	17.7
Romania	Hungary	RO-HU	1.7	6	28	2.8

† New pipeline may be necessary in the Adria LNG scenario, but not otherwise.

our welfare measure relative to its baseline value. Evaluating the benefit of all project combinations, as opposed to single projects in a selected order, allows us to capture both the complementarity and the substitutability between pipelines. The shortlisted projects are shown in Table 1.

Our main result is a list of the most beneficial project combinations based on welfare improvement *net of annualized investment costs*. We estimate investment costs using publicly available information on the projects (pipeline length and diameter) and benchmark unit investment costs published recently by the European Agency for the Cooperation of Energy Regulators (ACER). For example, the average unit investment cost is 1.06 million €/km for a pipeline with diameter 28”-35” (Table 8 in ACER [2015]), and 2.1 million €/MW for a new compressor station (Table 11 in ACER [2015]). Calculating with a length of 185 km and a single 18 MW compressor station (a typical size in the ACER database), the Greece-Bulgaria pipeline has a total investment cost of €234 million. This is equivalent to €15 million annually, assuming a 25-year lifetime and a 4% yearly discount rate (recommended parameters by ACER [2014]). Table 1 lists our estimates of the annualized investment costs for all the projects we include in the analysis.[24]

4 Results

4.1 Reference scenario

The stylized map of Europe on Figure 1 provides an overview of market prices in the *Reference* baseline scenario. It shows the modeled markets with a shaded background and the exogenously-priced outside markets (Norway, Russia, and Turkey) in white.[25] Consumption-weighted yearly average prices (in €/MWh) are displayed for a select set of countries. Darker shaded areas indicate higher prices.

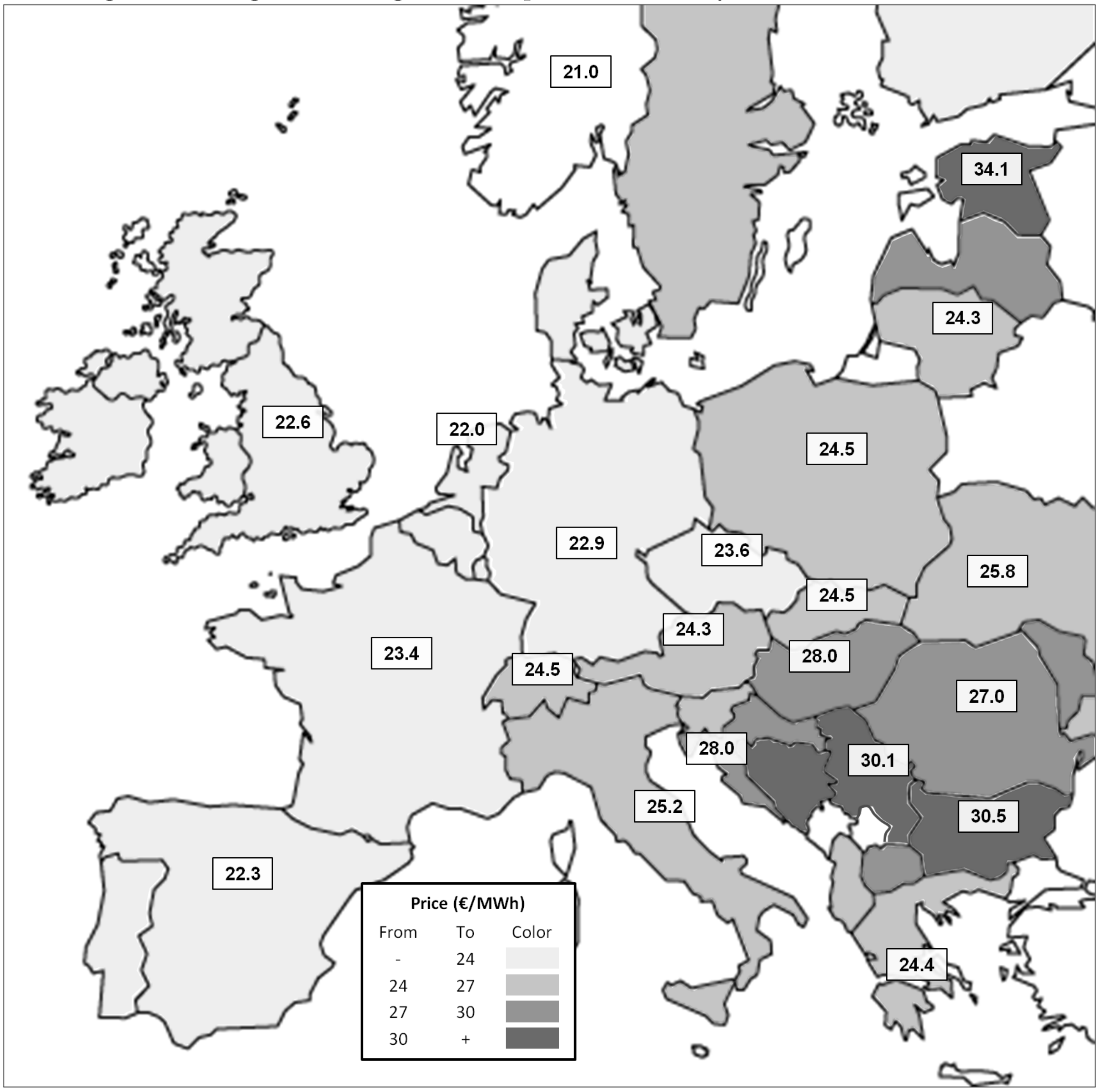
Markets in South Eastern Europe, including even Croatia and Hungary, have the most problematic supply-demand situations. The region lacks sufficient interconnection to Western Europe for cheaper gas to enter and push down prices. Greece is an exception, due to access to LNG and the Trans Adriatic Pipeline, but markets to its north see little of these benefits. Surveying the potential projects in Table 1, we would therefore expect

shortlist of the Energy Community in South Eastern Europe (Energy Community [2013]).

[24]Our cost figures are only imprecise estimates, since there is considerable (typically ±30%) variation around the mean benchmark values in the cited dataset. In an actual policy application, the numbers can be substituted by the cost estimates of the project promoter, for example.

[25]Belarus, Kosovo, and Macedonia are not included in the model.

Figure 1: Weighted average market prices in the *Reference* baseline scenario



the GR-BG, BG-RS, and HR-RS pipelines to allow for the largest increase in welfare as a result of increased trading and price equalization.

Starting from the baseline scenario depicted in Figure 1, we add all 127 possible pipeline combinations from Table 1 and find the competitive equilibrium in each case. We then aggregate social welfare (as measured by equation (4)) across all Central and South Eastern European markets, and calculate the annual net social benefit (ANSB) of an investment by subtracting the estimated annualized investment cost from the change in our welfare measure between the baseline and the after-investment scenario. We rank all pipeline combinations in decreasing ANSB order, and drop the ones that are dominated by another investment with a subset of the pipelines.[26]

[26]If building Pipelines A and B has a positive ANSB, but building Pipeline A by itself has an even higher ANSB, then we drop the two-element combination, because it is more costly and less valuable than the single pipeline investment. In the reverse case (when B adds value to A), we keep both pipeline

Table 2: Ranking of Investments in the *Reference* baseline

From	**To**	**Rank** 1	2	3	4	5
Bulgaria	Serbia	×				
Croatia	Hungary				×	
Croatia	Serbia					
Greece	Bulgaria	×	×			
Poland	Czech Rep.					×
Poland	Slovakia					
Romania	Hungary			×		
Welfare increase		60.3	19.2	0.9	0.0	0.0
Investment cost		27.6	15.0	2.8	2.4	12.5
Net social benefit		32.7	4.2	-1.9	-2.4	-12.5

All values are in million €/year.

Table 2 shows the main result of our simulations for the *Reference* baseline. Each column lists the pipelines included in the investment scenario, followed by the social cost-benefit balance. There are only two pipeline combinations with a positive net social benefit. The route from Greece to Serbia through Bulgaria is the most valuable investment, followed by a single pipeline from Greece to Bulgaria. The Romania-Hungary pipeline also yields some additional welfare for the region, but not enough to justify its cost. The pipelines in the 4^{th} and 5^{th} place do not increase welfare at all, because they connect markets with a price difference smaller than the cost of transportation.

In Table 3, we take a closer look at price and surplus changes resulting from the Greece-Bulgaria-Serbia pipeline investment. The first two columns show the before-after market prices, followed by changes in consumer surplus, producer surplus, net profit from long-term contracts, and infrastructure income. The latter category includes operating income and congestion rent on pipelines, LNG terminals, and storage units. We list the markets that are substantially affected in some dimension in separate rows, and add an *Other CSEE* line for the total welfare change in the region to match with the value in Table 2.

The largest price decrease is in Bulgaria, the closest one to the low-priced Greek market. Consumers in Hungary, Romania, and Serbia also benefit to some extent, while the rest of the region remains largely unaffected. Overall, consumers gain about €270 million, which is partially mirrored by losses on the producer and long-term contract holder side. The net effect on infrastructure income is neutral, although the area gets more of its gas from the south, which redistributes transportation profits from Hungary and Slovakia to Bulgaria and Greece. In the end, the countries benefitting most from the investment are the ones with jurisdiction over the territory where the pipelines run.

4.2 Change of Russian long-term contract delivery points

In this section, we explore hypothetical baseline and investment scenarios in which the contract delivery points of gas arriving from Russia are moved to the country where the gas enters the European Union. We will further assume that all transit routes from the east avoid crossing the territory of Ukraine. Instead, three other routes will be used: the Nord Stream pipeline with its current capacity under the Baltic Sea to Germany,

combinations in the list, because financial constraints might, for example, prevent the A + B investment, but allow for the less costly A investment to proceed.

Table 3: Major price and surplus changes from best investment in the *Reference* baseline (GR-BG, BG-RS)

Market	**Prices**		**Surplus gains and losses**				
	Before	After	Consumers	Producers	Contracts	Infrastructure	Total
Bulgaria	30.5	26.2	182	-51	-121	32	41
Greece	24.4	24.4	-4	0	2	32	30
Hungary	28.0	27.6	35	-3	0	-32	-1
Romania	27.0	26.9	16	-15	-1	0	1
Serbia	30.1	29.4	25	-1	-9	1	16
Slovakia	24.5	24.4	4	0	-3	-18	-17
Other CSEE			9	-1	-6	-12	-11
Total			267	-71	-139	2	60

Prices are in €/MWh, all other values in million €/year.

the Yamal pipeline through Belarus to Poland, and a not-yet-existing pipeline through Turkey to Bulgaria. For simplicity, we will refer to this set of scenarios as *No Ukraine transit.*[27]

We assume that all re-routed Russian long-term contracts are delivered to Germany, Poland, or Bulgaria. Specifically, the gas currently destined to Austria, France, Hungary, and Italy will first be sold in Germany, the Czech, Dutch, and Slovakian contract will be sold in Poland, and the gas transported through the Trans-Balkan pipeline will instead arrive through Turkey in Bulgaria. We calculate the revenues of contract holders as if they sold all the deliveries in these three countries, and allow traders in the spot market to profit from distributing the gas across the continent.[28]

In the spirit of a fair contract renegotiation, we assume that the (implied) wellhead prices of contracts are changed to reflect the difference in transportation fees between the new and the old delivery routes. As a result, if the gas found its way to its former target market, its border price (wellhead price + transportation cost) would be the same as before.

Figure 2 shows the equilibrium outcome of the *No Ukraine transit* baseline scenario. It uses a map of Europe similar to Figure 1, but the displayed numbers now represent differences in yearly average prices relative to the *Reference* baseline. Lighter shaded areas experience price decreases, darker shaded ones see their prices rise.

Changing contract delivery points does change market prices across the continent, although only mildly. Prices in Italy and most of Central and South Eastern Europe rise, while consumers in Western Europe become slightly better off. Prices in the smaller two designated delivery countries, Poland and Bulgaria, are especially depressed. Overall, Figure 2 suggests that a lack of cross-border capacity prevents some of the gas from reaching its nominal destination.

Taking the *No Ukraine transit* baseline as a starting point, Table 4 shows the pipeline combinations from Table 1 that are most beneficial to the CSEE region. Connecting Bulgaria to Serbia and Poland to the Czech Republic and Slovakia is the most valuable

[27] In the past, natural gas disputes between Russia and Ukraine have led to supply disruptions to consumers in Central and South Eastern Europe. The aborted South Stream and Turkish Stream projects have both sought to displace Ukraine as a transit country. In this scenario, we assume that a similar project in the south might eventually be completed, although recent political tensions between Russia and Turkey make this unlikely to happen until 2020.

[28] In the welfare expression, trading profit is actually turned into congestion rent collected by TSOs and SSOs.

Figure 2: Price changes from the *Reference* to the *No Ukraine transit* scenario

investment with an ANSB of €195 million. All other projects in the top 5 list are variations on the same idea: letting surplus gas "trapped" in Poland and Bulgaria find its way towards the markets that have previously been supplied through Ukraine.

Welfare calculations (available in the online appendix) show that changing the long-term contract delivery point results in a welfare loss of about €1.5 billion/year relative to the *Reference* baseline for all modeled countries together. Two-thirds of the loss is borne by Ukraine because of the re-routed transits. Contract holders also have to forgo about €1 bn/year by selling gas in areas with depressed prices. Consumers, on the other hand, end up being better off across the continent on average, even if the gains are unevenly distributed. Specifically, Italy, Ukraine, Romania, Hungary, and Austria are among the countries whose consumers lose most from the change, although this is more than offset by gains in Poland, Bulgaria, Germany, the Netherlands, and France. The overall losses in the CSEE region amount to €680 million/year. Around 30% of this amount can even

Table 4: Ranking of Investments in the *No Ukraine transit* and the *Adria LNG* baseline

From	**To**	**No Ukraine transit**					**Adria LNG**				
		1	2	3	4	5	1	2	3	4	5
Bulgaria	Serbia	×	×	×		×				×	
Croatia	Hungary						×			×	×
Croatia	Serbia						×	×	×		
Greece	Bulgaria							×		×	×
Poland	Czech Rep.	×		×	×						
Poland	Slovakia	×	×		×						
Romania	Hungary										
Welfare increase		237	184	150	144	97	164	113	96	140	98
Investment cost		43	30	25	30	13	41	24	9	59	46
Net social benefit		195	154	125	114	85	124	89	86	81	51

All values are in million €/year.

Table 5: Major price and surplus changes from best investment in the *Adria LNG* baseline (HR-HU, HR-RS)

Market	**Prices**		**Surplus gains and losses**				
	Before	After	Consumers	Producers	Contracts	Infrastructure	Total
Austria	24.2	24.1	10	-2	-7	-19	-17
Croatia	23.2	24.4	-31	10	0	173	153
Czech Rep.	23.6	23.5	5	0	-3	-17	-15
Hungary	27.9	27.0	94	-9	0	-55	30
Serbia	30.0	26.2	136	-4	-48	-17	67
Slovakia	24.4	24.2	11	0	-14	-38	-41
Other CSEE			47	-41	-6	-12	-12
Total			273	-46	-79	17	164

Prices are in €/MWh, all other values in million €/year.

be avoided by carrying out the most beneficial pipeline investment indicated in Table 4.[29]

4.3 Adria LNG terminal

The third baseline scenario simulates the completion of a long-planned LNG regasification terminal with a capacity of 6.5 bcm/year on the Adriatic coast of Croatia. By itself, the LNG terminal has a modest effect on the CSEE region. Average prices decrease by €4.8/MWh in Croatia relative to the *Reference* baseline (welfare increase of €80 million/year), but almost none of it flows over to neighboring markets due to the lack of interconnectivity. As a secondary effect, competition for LNG sources results in a loss of €20 million/year for Greece. Overall, the Adria LNG terminal brings a surplus of €48 million/year to the CSEE region without additional investments.

The right hand side of Table 4 shows the investments with the highest social return in the *Adria LNG* baseline. By far the most valuable project combination is the pair of pipelines from Croatia to Hungary and Serbia, which would increase regional welfare by €124 million/year, net of investment costs. Table 5 shows a breakdown of surplus changes in the countries most affected by the new infrastructure.

[29] One might argue that a change in contract delivery points affects the entire European continent to some extent, which will likely spark new investment projects other than the ones listed in Table 1. In this case, the rearrangement of transit routes will likely result in even smaller welfare losses for gas importing countries (although not for Ukraine).

Croatia benefits most from the two new export pipelines. Its income from the LNG terminal and the cross-border infrastructure rises by €173 million/year, largely consisting of profits on LNG imports. Consumers in Serbia and Hungary also derive massive benefits from indirect access to the LNG market. At the same time, producers and (especially) contract holders suffer some losses due to decreased prices. Pipelines carrying gas from the north towards Hungary and Serbia are also less heavily utilized. Similarly to the *Reference* baseline, the countries that derive most of the benefits from the projects are the ones involved in the investment decision.

5 Discussion

In this section, we discuss the lessons from our modeling exercise and point out potential pitfalls.

5.1 Welfare-based regional project evaluation

Our starting point was a *Reference* baseline scenario for 2020, depicted in Figure 1. In our model runs, the central areas of South Eastern Europe have the highest prices. Pipelines carrying gas into this region from lower-priced markets have the highest potential for welfare improvement.

The projects on the shortlist in Table 1 offer three distinct directions in which the region, roughly around the core of Serbia, could be supplied. The first one is from the north using expanded capacity from Poland to the Czech Republic and Slovakia. (Connections from Austria and Slovakia to Hungary already exist.) Our simulations suggest that this direction would not yield welfare improvements, because the three countries to be connected already have similar prices.

The second direction is from the south, exploiting the backhaul capabilities of the newly build Trans Adriatic Pipeline and low-priced LNG imports to Greece. In the *Reference* scenario, this is the most promising alternative, suggesting that the Greece-Bulgaria and Bulgaria-Serbia interconnectors could bring reasonable net welfare improvements across the region, especially in these three markets.

The third direction is from the west, using cross-border pipelines from Croatia to Hungary and Serbia. These projects could substantially increase welfare in the region, but only in connection with a (long-planned) LNG regasification terminal in Croatia that brings in new gas sources. Otherwise, the three markets to be connected have too similar prices for the new infrastructure to be worth building.

The welfare analysis in Tables 3 and 5 also illustrates the advantages of a model-based project evaluation. By comparing equilibrium outcomes with and without the new infrastructure, we can provide a nuanced picture of which market participants are likely to gain and lose from the investments across the larger interconnected system. It is possible, for example, that third countries get indirect positive effects from an investment that would not bring enough direct benefits to its sponsors otherwise. In this case, regional subsidies can be welfare-improving. The opposite outcome, where direct effects are large enough but indirect effects are negative, can also occur. In fact, many of our results fall in the second category, questioning the exact rationale for subsidizing the investments in Table 1.

We have also analyzed the net social benefits of PCIs including all modeled European countries in our welfare measure, rather than the CSEE region alone. It turns out that some of the welfare gain in CSEE is actually a redistribution from other EU countries, tilting the cost-benefit analysis against the new investments. In the *Reference* baseline, all investments yield net welfare reductions (the Greece-Bulgaria pipeline is only marginally unprofitable). The most beneficial project combinations in the other two baselines are also worthwhile investments from an EU point of view.[30]

As a robustness check, we have performed the analysis assuming lower demand for natural gas in 2020. (Tóth et al [2014]) A low-demand baseline leads to more uniform prices across the continent, decreasing the potential benefit of additional pipelines. Accordingly, we find that no project combination brings a positive ANSB in the *Reference* baseline, although either the Croatia-Hungary or the Romania-Hungary pipeline is on the verge of being profitable for the region. In the *Adria LNG* scenario, the Croatia-Serbia interconnector proves to be a robust project.

Our investment analysis has a number of caveats. In an actual policy application, one would extend the analysis for several years (possibly decades) after 2020, and examine alternative assumptions about our exogenous parameters (e.g. LNG prices, long-distance transportation infrastructure, contract characteristics). Ideally, there would be some feedback over time from short-run model outcomes into the assumptions driving the results in subsequent years. Such an analysis is beyond the purposes of this paper, however.

The competitive nature of our modeling approach does not allow us to analyze the effects of new investment on the market power of upstream, downstream, and infrastructure firms either. Such effects might be relevant, especially at the time of long-term contract negotiation. We also omit the analysis of short-run disruption scenarios, even though some of the cross-border pipelines could bring considerable benefits in extreme supply shortages. Our results should therefore be taken as an illustration of a regional welfare-based investment (or subsidy) decision method, rather than a definite list of recommended projects.

5.2 Modified delivery routes for long-term contracts

The second contribution of the paper is the analysis of a large-scale change in the delivery routes and destinations of long-term contracts from Russia. In our hypothetical (but not entirely unrealistic) situation, no gas arrives through Ukraine, resulting in a large loss of transit income for the country. The effect on welfare in the European gas sector is less drastic. The redistribution of welfare from Eastern to Western Europe is more noticeable than the overall loss resulting from the increased geographical mismatch of supply and demand. A substantial part of the negative effect can even be mitigated by north-to-south pipeline investments within the European Union.

Again, our conclusions are derived from a single baseline scenario, and a more nuanced picture would emerge from using a multitude of alternative assumptions. The necessary renegotiation of contract terms could, for example, lead to somewhat different outcomes in terms of contract prices or delivery locations.

There are two additional aspects worth discussing. Contrary to our assumptions about the border (destination) prices of contracts remaining the same as before, one could imagine that the current system of price discrimination by destination country would disappear if all contracts were to be delivered at an EU entry point. Although the CSEE region loses welfare when transits through Ukraine stop, it would benefit from

[30]All welfare calculations are available in the online appendix.

having its long-term supply contracts priced according to the market realities in Germany, for example.

With the change in delivery points to the EU border, the long-term capacity bookings on within-EU interconnectors (such as the Poland-Germany, Slovakia-Austria, or Austria-Italy pipeline) could also be freed up and made available for spot trade. These pipelines could even carry gas in the reverse direction with moderate additional investment. These changes would further contribute to the emergence of an integrated European gas market.

6 Conclusion

In this paper, we have introduced a competitive dynamic gas market model for the European consumer market and applied it to evaluate infrastructure projects in Central and South Eastern Europe. We based our project ranking on the resulting net increase in regional welfare taking into account all possible combinations of pipelines to be built from a shortlist of proposed PCIs. In a separate baseline case, we also used the EGMM to explore the consequences of changing the delivery points of long-term gas supply contracts from Russia to bypass the territory of Ukraine.

The goal of the paper is to outline an alternative project selection methodology, and not to provide an exhaustive analysis of costs and benefits. For reasons of conciseness, we have for example omitted the simulation of actual supply disruption scenarios.

One important element missing from our paper is the feedback from infrastructure investment into the pricing of long-term contracts. The destination-based price discrimination currently seen in take-or-pay contracts is largely consistent with the lack of alternative supply sources in countries that receive Russian gas at higher prices. As new pipelines bring gas from lower-priced regions, the bargaining position of these countries will also improve. Accounting for these effects in contract pricing is an important area for additional work on our modeling approach.

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