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Gas market distorting effects of imbalanced gas balancing rules: Inefficient regulation of pipeline flexibility

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ABSTRACT

This paper analyzes the value and cost of line-pack flexibility in liberalized gas markets through examination of the techno-economic characteristics of gas transport pipelines and the trade-offs between different ways to use the infrastructure: transport and flexibility. Line-pack flexibility is becoming increasingly important as a tool to balance gas supply and demand over different periods. In the European liberalized market context, a monopolist unbundled network operator offers regulated transport services and flexibility (balancing) services according to the network code and balancing rules. Therefore, gas policy makers should understand the role and consequences of line-pack regulation. The analysis shows that the line-pack flexibility service has an important economic value for the shippers and the TSO. Furthermore, the analysis identifies distorting effects in the gas market due to inadequate regulation of line-pack flexibility: by disregarding the sunk costs of flexibility in the balancing rules, the overall efficiency of the gas system is decreased. Finally, the analysis demonstrates that the actual costs of line-pack flexibility are related to the peak cumulative imbalance throughout the balancing period. Any price for pipeline flexibility should, therefore, be based on the related trade-off between the right to use the line-pack flexibility and the provision of transport services.

1. Introduction

Gas pipelines and compressors are the physical backbone of a natural gas market, and they can be used to make gas flow and to store it. There are, however, important trade-offs between these two possibilities to engage the gas infrastructure. If this dual functionality, which is embodied by line-pack flexibility, is neglected, negative effects are carried into the gas commodity and gas transport market. Yet, almost no reference to the problems with line-pack flexibility can be found in the literature. The problem is further complicated because aspects of investments, network operations and balancing markets have to be dealt with simultaneously. Therefore, this paper aims to shed some light on the problem setting through analysis of the economic consequences of the trade-offs between the transport function and the flexibility function of the pipelines in the context of the European liberalizing gas markets. The pipeline flexibility can be seen as a positive externality of the transport network design, on the one hand; the right to use this flexibility decreases the available transport capacity, on the other hand. So, the benefit of flexibility in the timing of injections and withdrawals that is possible because of line-pack flexibility should be weighed against the harm of reducing available transport capacity in order to assure the flexibility (Coase, 1960). In Section 2, we explain in detail the technical relationship between the two functions of the infrastructure. It is evident that the line-pack flexibility has an economic value (for different actors), and that this value can be bigger than the harm provoked by its use. Still according to Coase (1960, p. 7): "*It is necessary to know whether the damaging business is liable or not for damage caused since without the establishment of this initial delimitation of rights there can be no marked transactions to transfer and recombine them.*" In Europe, the right to use the pipeline flexibility is defined by the balancing rules[1] and the network code, as underlined by the European Regulator's Group for Electricity and Gas (ERGEG, 2009).

The Coase theorem further specifies that the allocation of rights has no welfare implications if there is a workable market and price

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[1] In gas markets where transport capacity is sold based on bilateral contracts (e.g. Australia, Brazil and US) the issues addressed in this paper are of less interest. The bilateral coordination mechanism allows the rights and obligations of the players as well as the time and geographical flexibility to be defined in a heterogeneous manner (Colomer et al., 2009; FERC, 2000; Hallack et al., 2010). This is very different from Europe where the gas network offers services with predefined and regulated characteristics for all users.

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signals. However, in the European gas transport case, the transport function and the network flexibility are considered the monopoly of the network operators, and the related services are considered regulated services with regulated tariffs. Nevertheless, the problem of the dual function has been raised many times by institutions such as the European Commission's DG Transport and Energy (2005), ERGEG (2006, 2009), and Gas Transport Europe (GTE, 2009). A clear proposition on how to take it into account in the balancing tariffs has not been formulated, though. Some national network operators, e.g. GRTgaz in France, have also been concerned about the issue (CRE, 2009a; GRTgaz, 2009). GRTgaz particularly called attention to the problem of whether investments caused by unbalanced shippers, who are the users of transport services, should affect the gas transport tariff of all shippers. As will be shown in Sections 2 and 3, line-pack flexibility and balancing are closely related. Keyaerts et al. (2008) and Lapuerta (2003) have shown the possible negative impact of balancing tariffs on the gas market competition, and how these balancing mechanisms potentially increase entry barriers for small shippers. Moreover, many policy makers have advocated that the balancing tariffs should reflect costs and that the offering of a regulated monopoly service should not be a profitable business for a network operator (OFGEM, 2003).

The tariffs and balancing rules should reflect the actual costs of line-pack flexibility, which is currently the main tool for *ex post* gas network balancing. *Ex post* balancing means that balancing is done by the TSO within the framework of the balancing rules, whereas *ex ante* balancing means that the shipper contracts flexibility instruments on beforehand to balance himself. The line-pack costs include variable costs of pipelines and compressors as well as sunk costs of this infrastructure. The cost decomposition of pipelines between its two different functions of transport and flexibility is complex. The supply function of two services produced by a common network infrastructure can be classified by the classic microeconomics theory as a multi-product monopoly. Moreover, the transport and storage services offered by this multi-product monopoly are part of different markets (as both have different substitutes) even if the production costs of the two services are dependent (Tirole, 1988). Although the gas network service can be considered a natural monopoly, the pipeline flexibility is competing with other real or potential sources of flexibility such as contract flexibility and other storage mechanisms (IEA, 2002).

Therefore, it is not sure whether pipeline flexibility should be regulated at all. The market for flexibility services is principally a competitive market. Nevertheless, many flexibility services remain (partly) regulated in Europe. The case for regulation of line-pack flexibility is strong, though, because the underlying infrastructure belongs to the regulated part of the gas market. An inefficient tariff for pipeline flexibility can result in a misallocation of resources in the flexibility market, which subsequently raises a need for regulation to develop other flexibility like storage. Therefore, inefficient regulation of pipeline flexibility impedes the development of a truly competitive flexibility market.

Because of this complexity, the understanding of the trade-offs between the transport function and the storage function of the pipeline infrastructure is a key issue to improve network regulation. The proper understanding of this allows the opportunity costs of time flexibility to be determined in a similar way as has been done by Lapuerta and Moselle (2002) for an analogous problem regarding geographical flexibility. These authors use opportunity costs to compare different capacity systems with regard to flexibility rights and tariffs, and to evaluate the market consequences. Opportunity costs have also been applied to evaluate externalities of energy markets (Oren and Sioshansi, 2004; Pineau and Lefebvre, 2009; Rious et al., 2008a, 2008b). The definition of such costs is essential to determining an efficient tariff because in the absence of a clear market price, it is the tariff rules that define the allocation of rights to use the monopoly infrastructure, addressing the Coase problem as a feasible second best (Glachant, 2002; Glachant and Perez, 2007).

Therefore, this paper aims to contribute to the discussion about the network tariffs exploring the economic consequences of the trade-offs between the gas pipeline transport capacity and pipeline storage. Furthermore, an important consideration is raised concerning the role of peak cumulative imbalances in solving the non-trivial problem of pricing line-pack flexibility. Indeed, in an unbundled market, the bundling of the two very different services of the pipelines is challengeable, and a separate price for line-pack flexibility can increase transparency and efficiency in the market. In order to present this contribution, the next section explains the origins of line-pack flexibility and its uses. In Section 3, the economic value and costs of line-pack flexibility are explored for the TSO and the shippers. The consequences of "imbalanced" gas balancing rules and tariffs on the regulated and the potentially competitive parts of the gas market are discussed in Section 4. Finally, Section 5 presents the main conclusions and puts forward recommendations for gas market policy.

2. Line-pack flexibility: origin and uses

The ability of gas networks to store natural gas inside pipelines is a consequence of the physical properties of the transport network where the volume gas flow can vary according to the pressure differential as explained in the technical literature (e.g. Eberhard and Hüning, 1990). The transport operator can decide how much gas to transport and how much gas to store taking into account some technical limits. These technical limits determine the line-pack flexibility. We clearly distinguish between the concepts of "line-pack", which is the total volume of gas present in a pipeline section, and "line-pack flexibility", which is the amount of gas that can be managed flexibly by controlling the operation pressure levels between a minimal and a maximal level (Fig. 1). The following sections explain how this flexibility is produced in the network as a consequence of the gas transport dynamics, and how this flexibility is useful for managing a gas network system.

2.1. Production of line-pack flexibility

The dynamics of gas transport are described by Eq. (1) in which Q stands for the volumetric[2] flow rate (m^3/s), D represents the diameter (m) of the pipeline section of length L (m), and p_{in} and p_{out} are the pressure (Pa) at the inlet of the pipeline and at the outlet of the pipeline, respectively. The constant c represents material and gas characteristics such as pipeline roughness and gas density, and is also dependent on the units chosen for the other parameters

$$\dot{Q} = cD^{2.5}\sqrt{\frac{p_{in}^2 - p_{out}^2}{L}} \tag{1}$$

$$V_{LPflex} = w\left(\frac{p_m}{K_m} - \frac{p_{m'}}{K_{m'}}\right) \tag{2}$$

$$p_m = \frac{2}{3}\left(\frac{p_1^3 - p_2^3}{p_1^2 - p_2^2}\right) \tag{3}$$

[2] Volumetric flow rate (Q) under reference standard conditions (T=288 and p=101,325 Pa) is equivalent with mass flow rate (m), differing only by a constant reference density.

Basically, the gas flow rate is related to the difference of the quadratic pressures at both ends of the pipeline section, and not the absolute levels of the pressures. Pipelines can be operated at a range of pressures that are limited at the upper bound by a maximal operating pressure (p_{emax}), which is determined by the material characteristics and at the lower bound by a minimal operating pressure (p_{dmin}). This lower bound is the pressure that ensures flow by compensating friction or it can be determined by contractual arrangements for a certain delivery pressure.

The system operator can ensure the safe operation of the pipeline network by operating within a pressure band defined by maximal and minimal pressures. This operational flexibility in gas transport networks results in the ability to store gas in the pipelines by using line-pack flexibility, while ensuring normal gas transport. Both the pressure drop (p_1p_2 or $p_{1'}p_{2'}$) required for the transportation service and the available storage potential (area $p_1p_2p_{2'}p_{1'}$) are illustrated in Fig. 1.

The available line-pack flexibility, expressed in standard cubic meters, is determined by Eq. (2) in which w is a constant that is dependent on the geometric volume of the pipeline and the chosen reference conditions. Basically, the storage potential depends on the difference between the higher average pressure p_m (Pa) and the lower average pressure $p_{m'}$, which are calculated according to Eq. (3). K_m and $K_{m'}$ are compressibility numbers (dimensionless) corresponding to p_m and $p_{m'}$, respectively. The lower average pressure depends on the entry pressure and the delivery pressure that correspond to the desired transport flow. If the full pressure differential is required to make the gas flow, there remains no storage potential, whereas if there is no flow the full geometric volume of the pipe can be used to store compressed gas.

2.2. Use of line-pack flexibility: pipeline storage

Line-pack flexibility is produced by exerting the still available pressure difference and results in the storage of gas inside the pipeline. The basic principle of storage is that one can only withdraw what has been injected before. Therefore, line-pack flexibility operates like a buffer that is filled first, and emptied at a later time. This *buffer* concept has been defined by Lapuerta as the part of the line-packing, meaning the total volume of gas in the pipeline, that can be used without any safety problem (Lapuerta, 2003, p. 66): "*at any point in time, the available buffer is the difference between line-pack at that time and the minimum safe level of line-pack*". In other words, "*the available buffer is the maximum amount that line-pack can fall within-day from its current level without introducing a positive probability of supply failure*". In the framework of this paper, the line-pack buffer at any time is equivalent to the used line-pack flexibility. In the remainder of this paper the concept of *line-pack flexibility* refers to the availability of flexibility and the "service"; whereas *line-pack buffer* refers to the actual use of the flexibility service.

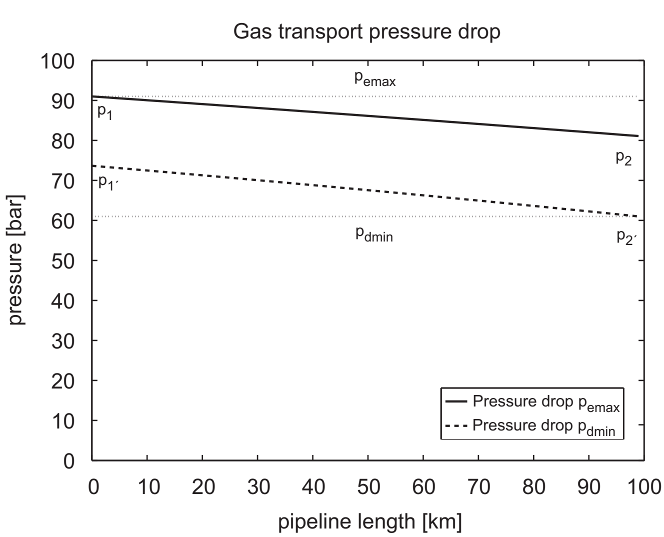

Fig. 1. Line-pack flexibility: the area defined by $p_1p_2p_{2'}p_{1'}$ represents the storage potential in the pipeline while simultaneously ensuring the transport corresponding to the pressure differential $p_{1'}^2 - p_{2'}^2$ at the lower boundary.

Line-pack flexibility and the gas transport service are interdependent services of which the pipeline flexibility accommodates a different time pattern for the matching of gas injections and withdrawals (Fig. 2).

The examples in Fig. 2 assume constant demand over the course of a day. In Fig. 2a the shipper injects all gas during the first half of the day, building up a buffer for withdrawal during the second half of the day (Fig. 2b). If the shipper injects late (meaning in the second half of the day) gas is withdrawn from the line-pack buffer during the first 12 h (Fig. 2c and d). In both examples the shipper needs entry capacity of 200 (m^3/h) and exit capacity of 100 (m^3/h). So, the shipper counts on the pipeline storage to balance the actual loads.

To allow the withdrawal of gas before the injected gas has reached the withdrawal point (Fig. 2c and d) the line-pack buffer has to be used to satisfy demand. This buffer needs to be created and kept in storage within the physical boundaries of the pipeline. Therefore, part of the capacity (100 m^3/h) cannot be allocated to transport services. The same logic can be applied the other way around: if the gas is injected in the pipeline by a shipper before a withdrawal demand arises (Fig. 2a and b), and the flexibility is guaranteed, it is necessary to keep gas inside the pipeline until there is a demand for withdrawal by that shipper. It cannot be used by a second shipper, unless there is a guarantee that gas will be available for delivery to the first shipper when he demands it. The part of the pipeline committed to gas buffering is determined by the cumulative imbalance swing (difference between highest cumulative peak and lowest cumulative dip), and is equal to 100 in both illustrations in Fig. 2. Based on these technical relations one expects trade-offs to occur between offering line-pack flexibility and selling transport capacity.

2.3. Managing a set of pipelines: balancing

Therefore, the line-pack flexibility enables the network operator to store gas inside the pipelines to facilitate the matching of gas supply and demand over time. The line-pack flexibility is particularly suited to immediately accommodate short lived imbalances between demand and supply. This subsection briefly discusses gas network balancing in order to facilitate the understanding of some of the economic issues that are dealt with in the subsequent sections about balancing.

Physically, an imbalance occurs whenever the amount of gas injected in the system (m_{in}) is not equal to the gas taken from the system (m_{out}), disregarding losses such as gas consumption in compressors along the pipeline. The correct equation reads

$$\dot{m}_{in} - \dot{m}_{out} = \frac{\partial(\rho V)_{storage}}{\partial t} \tag{4}$$

The right hand side term in Eq. (4) reflects the change over time of the gas mass stored inside the pipeline by means of line-pack flexibility. The imbalance is then reflected in that storage term, in which V represents the geometrical volume (m^3) of the pipeline section and ρ the gas density (kg/m^3). Therefore, line-pack flexibility makes balancing gas networks an intertemporal problem because the short term storage in pipelines allows matching demand and supply over a time interval, rather than instantaneously. Although

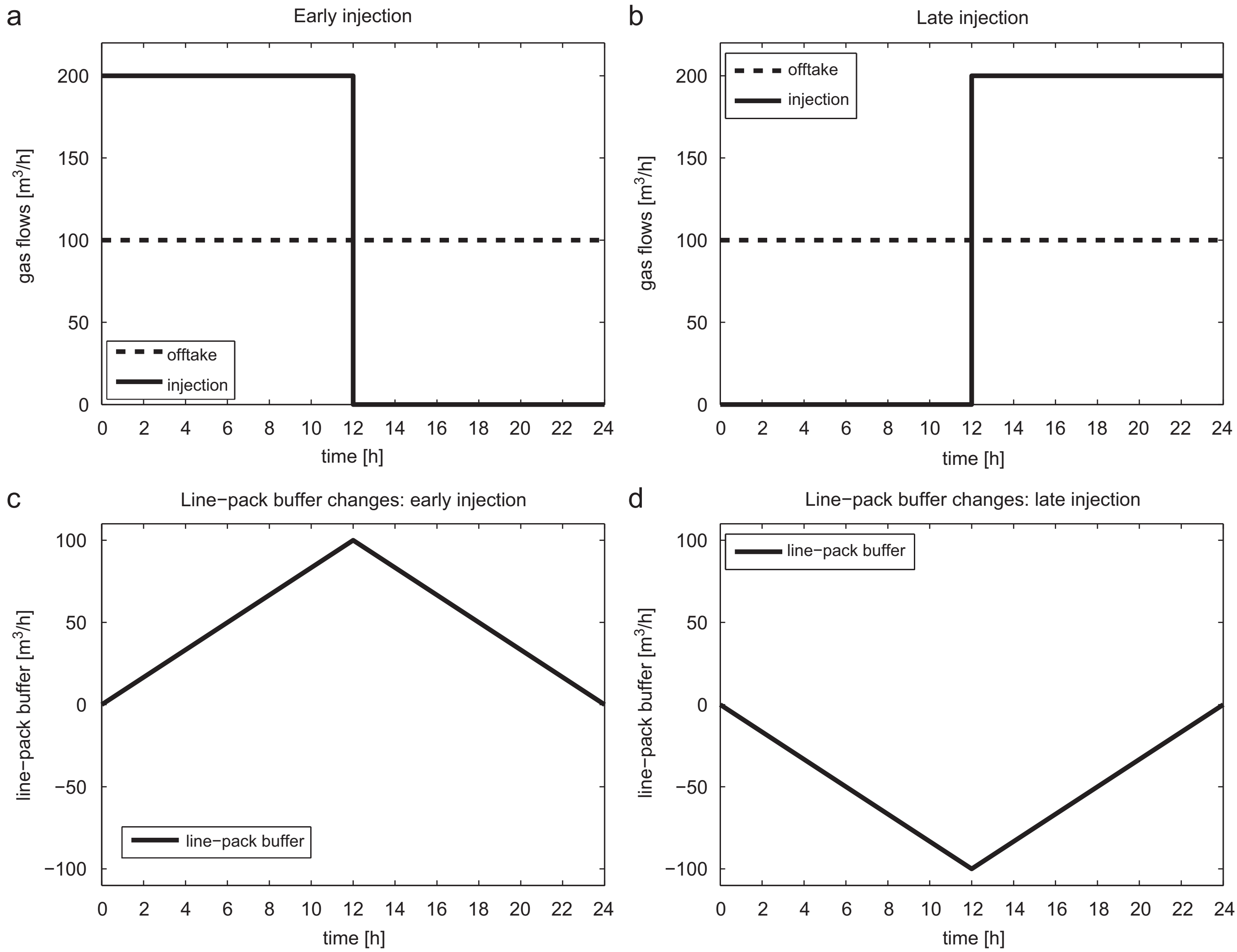

Fig. 2. Accommodation of different gas injection and offtake time pattern: (a) early injection (m^3/h), (b) line-pack buffer creation (m^3/h), (c) late injection (m^3/h), and (d) line-pack buffer extraction (m^3/h).

the system operator is ultimately responsible for the safe operation of the network, the shippers should balance their gas injections and withdrawals themselves. These balancing rights and obligations of shippers and network operators in Europe have been defined in (national) balancing rules.

2.4. *Conclusion on the technical aspects of line-pack flexibility*

Technically, line-pack flexibility is available in any pipeline with a non-flat transport demand profile. To use the pipeline flexibility, the line-pack buffer has to be produced first, though. This buffer is basically just local pipeline storage, which is very useful to manage a gas network. However, as the flexibility needs to be produced and can be applied for different uses there are real economic values and costs involved, which are further discussed in the next sections.

3. Economic value and costs of line-pack flexibility: trade-offs

Joskow (2007) argues that the creation of well functioning liberalized gas markets is technically not much of a challenge because of the ability to store gas along the supply chain. However, we argue that the presence of flexibility makes the economics of the gas market liberalization very challenging. Line-pack flexibility in particular is a service with special characteristics that cannot be discussed without taking notice of the whole gas transport system.

In the absence of an efficient market regulated tariffs reflecting long term marginal costs are a second best solution for the gas transport system as described by Kahn (1971) and Spulber (1989). In Europe, this has resulted in line-pack flexibility being regulated by the balancing rules, which according to EU rules (European Union, 2009a, b) should provide appropriate balancing incentives to shippers. Furthermore, these rules advocate that balancing charges shall be cost reflective. However, balancing rules allocating free line-pack flexibility and balancing charges based purely on gas prices can be observed throughout Europe, even if the gas spot market has not been the main tool to physically balance the system.

3.1. *The economic value of line-pack flexibility*

The fundamental value of line-pack flexibility can be attributed to its buffer function to quickly cover temporal imbalances between supply and demand as discussed and illustrated in Section 2. Technically, pipeline storage reflects physical “imbalances” between gas entering and gas leaving the system. The economic definition of a gas imbalance, on the other hand, depends on the balancing period, which is the time interval over which real gas injections and withdrawals should match and this interval can

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theoretically last from a second to an hour or even a day or a month. Taking into account that the value of gas demand varies in time, and that the production or import of gas is often less costly when it is flat, there is a value to facilitate the matching of gas demand and gas supply over time. This value is even increasing due to the development of short term gas demand for electricity generation with gas fired power plants (GFPP) (Hallack, 2010; Lapuerta, 2003; Roques, 2008).

Moreover, the economic value created by the flexibility to store gas inside the pipeline and to transport gas through a full or empty pipeline can be appropriated by different players: the system operator can use this property to minimize its pipeline investments, whereas shippers can use it for price arbitrage and load management.

3.1.1. Line-pack value for a system operator: network investment

The system operator is responsible for network investment and thus for the dimensioning of the network. Therefore, an efficient TSO maximizes the sale of transport capacity while minimizing the capacity that it builds. Line-pack flexibility helps the TSO to avoid over-investment, meaning an investment in capacity that will not be used during the pipeline deprecation horizon.

In a network based on entry/exit schemes, transport capacity is marketed through the separate selling of entry capacity and exit capacity, as detailed by Lapuerta and Moselle (2002) and KEMA (2009). Table 1 provides again a basic example of entry flows (supply) and exit flows (demand) for two periods Δt_1 and Δt_2, each lasting 1 h. The demand varies between 400 (m^3/h, fictional numbers) in the first period and 600 in the second period. For the supply there are two options. Option 1 exists in supplying exactly the demanded flows in each period, whereas option 2 takes into account the available line-pack flexibility and supplies 500 in every period.

The exit capacity offered by the system operator should allow the delivery of gas during the peak period. Therefore, the exit capacity needs to amount to 600. The system operator can now choose the amount of entry capacity it offers to the gas suppliers. The straightforward solution is to allow the suppliers to follow the demand with the supply flows and offer a capacity of 600 at the entry as well. In that scenario the upstream pipeline infrastructure needs to be designed to deliver 600 at the entry point in period 2 (either by pipeline flow or storage).

If the system operator takes into account the presence of line-pack flexibility, on the other hand, it invests in an entry capacity of 500 that is fully used in both periods. Moreover, this solution allows optimizing the investment in the upstream infrastructure to deliver a stable flow of 500 in the two periods instead of building a transport capacity to handle the production/import peak of 600.

The network operator confronted with demand A observes an economic value of storing 100 m^3 that is equivalent to the investment differential to make available an entry capacity of 600 or 500 m^3/h to face the same demand. The marginally saved investment constitutes a negative opportunity cost for the TSO. This benefit should be transferred to all network users through reduced transport tariffs.

3.1.2. Line-pack value for a shipper: load management and price arbitrage

In a liberalized gas market, the shippers, who can be any gas buyer or seller, are profit maximizing market players. They buy their gas as cheap as possible and sell it as expensive as possible (or use it when it has a bigger economic value). This means that in a market context shippers prefer to buy gas on a flat-rate basis, avoiding additional costs associated with volatile production, or when prices are lower due to lower demand in that period. The gas is then preferably sold in peak periods, which have higher prices (IEA, 2002).

So, if an opportunity turns up for a shipper to buy cheap gas in Δt_1, inject it in the pipeline and sell it at a premium in Δt_2, the shipper will be interested in using the line-pack flexibility to arbitrate between prices. Evidently, a shipper could also sell gas from the line-pack buffer in Δt_1, if gas prices are high, and inject in Δt_2, when gas has a lower price to match his purchase and sales portfolio.

In Table 2 the peak demand is in period 1 and the off-peak demand in period 2. There are again two options for supply. Option 1 exists in supplying exactly the demanded flow in each period, whereas option 2 uses the line-pack flexibility, to cover the difference over time.

Again, the exit capacity offered by the system operator should allow the delivery of gas during the peak period. Therefore, the exit capacity needs to amount to 600 (m^3/h). If the shipper is not obliged to balance over Δt_1 (e.g. he should only balance over $\Delta t_1+\Delta t_2$), the system operator becomes responsible and assumes the costs for the safe operation of the network. In other words, the system operator cannot be sure that the gas will be completely injected in Δt_1 because the shipper has the flexibility to inject only 400 or 500 and still take-off 600. Similar to the observations already made in Fig. 2, the system operator needs to have gas in pipeline storage from period Δt_{t-1} to allow the withdrawal of 600 in Δt_1 before the shipper makes the matching injections in Δt_2.

Therefore, the economic value of pipeline flexibility for the shipper consists of the possibility to arbitrate between injecting (buying) gas when it has a lower price and having gas withdrawn (selling) when it has a higher economic value. The TSO, as the safeguard of gas system integrity, anticipates this withdrawal and keeps gas in pipeline storage (Lapuerta, 2003). Evidently, this valuable flexibility has economic costs too.

3.2. The costs of line-pack flexibility for the TSO

The fixed cost of line-pack flexibility for the TSO can be evaluated by the part of the pipeline cost used to store gas in order to address unbalanced situations, or by the opportunity cost of the line-pack flexibility, which is the market value of the available transport capacity with and without bundled line-pack flexibility. The examples from Fig. 2 and Tables 1 and 2 clearly illustrate this argument: to sell the firm withdrawal capacity of 600 m^3/h, the TSO needs to ensure that the pressure level in the pipeline will not drop below the pressure level required for the load buffer, meaning that the pipeline company needs to keep gas in

Table 1
Example of demand and supply flows for two hourly periods (Δt_1 and Δt_2) under different capacity offers, injection before withdrawal (author elaboration).

m^3/h	Demand A Exit cap 600	Supply option 1 Entry cap 600	Supply option 2 Entry cap 500
Δt_1	400	400	500
Δt_2	600	600	500

Table 2
Example of demand and supply flows for two hourly periods (Δt_1 and Δt_2) under different capacity offers, withdrawal before injection (author elaboration).

m^3/h	Demand B Exit cap 600	Supply option 1 Entry cap 600	Supply option 2 Entry cap 500
Δt_1	600	600	500
Δt_2	400	400	500

storage that might be withdrawn before a matching injection is made.

The opportunity cost of pipeline flexibility, therefore, depends on the amount of capacity that is unavailable for transport services due to its commitment to buffering. This amount is related to the biggest cumulative swing in either direction as explained in Section 2. With reference to the numbers in Fig. 2b and d, 100 m^3/h of pipeline capacity is committed to pipeline flexibility and cannot be sold if flexibility is bundled with transport capacity. The market value of this amount of unavailable transport capacity defines a trade-off cost for the infrastructure.

In the vertically integrated gas industry all flexibility costs were inserted in the integrated company's pool of costs to supply gas to consumers. In the unbundled European gas industry the picture changed. Nowadays, the transport network is managed by a separate system operator that is responsible for the execution of the transport service and the system balancing. Both services physically depend on the pressure management as explained in Section 2.

Because of its obvious relationship with the pressure management of the pipeline system, line-pack flexibility in Europe is controlled by the system operator. The basic short term trade-off for this system operator exists in the mutually exclusiveness of offering a unit of pipeline storage versus offering a unit of pipeline transport, within the framework of a physically limited pipeline capacity. Furthermore, actual pipeline use by the operator depends on pre-defined (national) regulation that provides a framework for all services offered by a TSO. These network codes explicitly or implicitly determine the amount of line-pack flexibility that is kept out of the market by the TSO to guarantee bundled flexibility for each unit of transport made available.

The shippers (suppliers), on the other hand, hand over gas to the system operator at entry points and take back control over the gas at exit or delivery points. They actually cause imbalances if their injections do not match their withdrawals. "*In a liberalized market, system balancing is achieved through the interaction of networks users and the TSO. Whilst network users should aim to minimize and be obliged to take the financial responsibility for any deviation between the inputs and off-takes, the TSO remains the only instance that is able to ensure the physical balance of the overall network*" (KEMA, 2009, p. 34). Therefore, national balancing rules establish balancing charges in order to transfer the costs of imbalances from the system operator to the shippers who have caused the imbalances and to incentivize the shippers to balance their flows *ex ante* by means of storage and other flexibility contracts on the market.

3.3. *The cost allocation of line-pack flexibility: the balancing mechanism*

In Europe the line-pack costs are in part socialized by means of transport tariffs and in part allocated to shippers through balancing rules, charges and tariffs. Line-pack flexibility is often the main balancing tool applied by all TSOs. Therefore, we can basically argue that balancing charges should at least pay the costs of line-pack.

The cost impact of *ex post* balancing services offered by the TSO is technically dependent on peak cumulative imbalances as has been demonstrated in Section 2.2. A shipper, though, only has to balance his position over the defined balancing period and the balancing payments depend on the charges asked for this end-of-period imbalance. The temporary imbalances within the balancing period aggregate into a cumulative line-pack swing that represents the actual balancing cost for the TSO. The longer the balancing period, the higher the balancing cost for the TSO can become due to the accumulation of imbalances within the timing delay for which the TSO is responsible. These costs are socialized through network tariffs. The better the balancing charges reflect the actual system balancing costs, the more efficiently these charges incentivize shippers to choose the most economic balancing tool, *ex ante* or *ex post*. Given the demonstrated role of the maximal swing of cumulative imbalances, any cost reflective price for *ex post* balancing charges should explicitly or implicitly refer to peak cumulative imbalances.

A typical balancing mechanism specifies time and space boundaries in which the shipper has to balance his position. Moreover, some balancing rules add tolerance margins offering the shipper some margin to have imbalanced positions without any penalization. Furthermore, the balancing mechanism specifies balancing charges that should reflect the costs incurred by the system operator to balance the transport system and sometimes it specifies extra charges just to penalize and incentivize imbalanced shippers.

In actual EU balancing mechanisms, however, line-pack costs are rarely[3] included in the balancing charges even if line-pack flexibility is the first tool applied by the TSO to balance the system (ERGEG, 2007; KEMA, 2009).

3.3.1. *Balancing mechanism definitions*

First, the definition of the balancing period, which is the time interval over which gas injection and withdrawal should be balanced by the shipper, is a key definition because it establishes the division of balancing responsibilities between TSO and shippers. Inside the balancing period the TSO carries out balancing at no cost for the shipper, but at the end of the period the shipper should balance himself by means of *ex ante* or *ex post* balancing instruments. If the balancing period is an hour, injection and withdrawal should be balanced every hour; whereas in a daily balancing mechanism the shipper should only balance every 24 h. Therefore, and referring to the examples in Fig. 2, the system operator needs to provide gas from (pipeline) storage in case a shipper withdraws gas before he injects, and needs to keep gas in storage that was injected for withdrawal at a later time.

Second, the definition of the imbalances that are subject to balancing charges and the size of these charges is not homogeneous in Europe. Imbalances within the balancing period have no financial consequences for the unbalanced shipper. In other words, flexibility costs within the balancing period are socialized. Some countries (e.g. Belgium and the Netherlands), however, have added rules to limit the free flexibility inside the balancing period (e.g. hourly limits in a daily balancing system). These rules are meant to discourage huge differences between injections and withdrawals over smaller intervals within the formal balancing period. At the same time they implicitly try to limit the peak within-day cumulative imbalance. Furthermore, balancing rules have very different approaches to dealing with tolerance levels and penalty charges. For instance, in some balancing mechanisms there are different prices according to the size of the imbalance. Imbalances below a certain threshold are charged a price P_{ref} or even no price at all, whereas larger imbalances are considered excessive and are subject to a price P_{ref} plus a penalty x. The small imbalance that is less expensive or free is defined by the tolerance levels, which actually reflect the availability of line-pack flexibility. By offering tolerances the system operator commits to keeping a certain level of line-pack flexibility for storage services at the cost of selling this capacity for the purpose of transport. In systems that have a smaller balancing interval or do not offer tolerances, the system operator can sell more capacity for transport services.

[3] The Spanish balancing rules is a rare exception that explicitly refers to the line-pack capacity that is bought bundled with transport capacity by the shipper. This line-pack capacity delimitates the tolerated amount of imbalance (CNE, 2008).

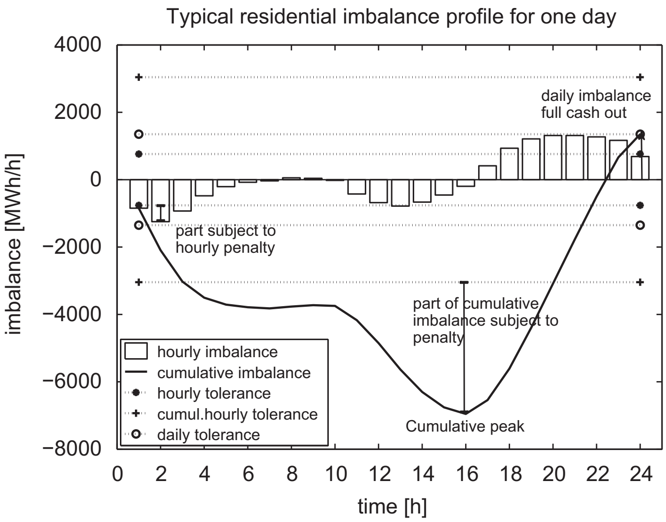

Fig. 3. Illustration of a daily balancing mechanism with additional within-day charges and tolerances.

We highlight again that the cost of different balancing rules should be dependent on the opportunity cost of unavailable pipeline transport capacity.

Third, there exist different pricing systems to set up balancing charges. Most European balancing mechanisms base balancing charges solely on gas prices, as is recommended by ERGEG (2009). In other words, by the end of the balancing period a shipper should not have any remaining imbalances. If the shipper has imbalances, he will be subject to pay the cost for the equivalent amount of gas as if that gas had been bought or sold on the market.[4]

An illustration (Fig. 3) of a daily balancing mechanism with additional within-day rules and tolerances clarifies the definitions; a more elaborate discussion about national balancing mechanism designs in Europe is available in Appendix A. A basic daily balancing mechanism only cashes out the end-of-day imbalance, which is the last point of the full line. The bars represent the free intra-day flexibility for the shipper. The addition of within-day penalties for excessive, meaning beyond the tolerated levels (dashed lines), hourly imbalances and for the peak cumulative imbalance over the day, implies that within-day flexibility is no longer costless for the shipper. Also, the cumulative peak in the figure illustrates well that this peak within-day cumulative imbalance can be substantially bigger than the end-of-day imbalance that gives cause to balancing charges in a basic system.

If the balancing period would be an hour, on the other hand, every single bar would represent an imbalance that causes a balancing charge. Within-hour imbalances, not shown in the figure, could still occur, but are expected to be much smaller on a cumulative basis than the cumulative within-day peak.

Taking into account the above definitions, balancing mechanisms can be further divided in regulated and market based mechanisms. Although the EU regulated charges should reflect the actual balancing costs of the system, these charges do not include, at least not in a public and transparent manner, the physical costs of the network as discussed above. On the contrary, the charges are mostly based on gas prices and often appear to be solely designed to steer shipper behavior with penalties. On the other hand, balancing charges that are entirely based on gas market prices actually imply the impossibility to use line-pack flexibility as a tool to store gas for price arbitrage. Indeed, such balancing charges come down to an obligation for the shipper to have bought or sold all the gas in the pipeline at the gas price of the period, whereas price arbitrage has the objective of trading gas at different prices in different periods.

3.3.2. *Inadequate cost allocation leads to cross-subsidies*

The European practice (see Appendix A for an overview) of providing a longer balancing interval and offering free tolerances actually means giving free short term storage or free short term flexibility. "Free" in this context means that the costs are socialized in the balancing or network tariff. So, shippers who need more flexibility, especially within-day, pay less than the costs they cause to the network system. Shippers who require less flexibility pay more than the costs caused by their actual use of the flexibility as described above. Consequently, this free line-pack flexibility may inhibit the development of other less costly short term flexibility sources, as will be discussed in Section 4.

Intra-day flexibility becomes more and more important because of the increasing participation of gas-fired power plants in the gas market. This trend has been observed in recent years and is expected to continue in the next decade (Hallack, 2010). The interdependence of gas and electricity demand profiles (Keyaerts et al., 2010) through these gas-fired power plants increase the short term volatility of gas demand as can be observed in the example of Fig. 3. Thus, in a daily balancing model, the flexibility that needs to be provided to accommodate the intra-day demand variability of gas-fired power plants is paid for by all gas shippers, and thus all gas consumers (Costello, 2006; CRE, 2009a). This cross-subsidization decreases the efficiency of the overall gas system efficiency and should, therefore, be addressed.

In Fig. 4, the changes of hourly gas demand of combined cycle gas turbines (CCGT) are compared with the demand changes of the local distribution zones (LDZ) of the UK. It can be observed that the changes are much bigger for the CCGT demand, with the biggest negative disequilibrium (withdrawal exceeds injection) amounting to -0.82 million cubic meters (mcm), and the biggest positive disequilibrium (injection exceeding withdrawal) amounting to 1.06 mcm. The respective peaks for LDZ demand are -0.37 and 0.42. The daily swing (the difference between the positive and negative hourly peaks) is 1.88 mcm for CCGTs and 0.79 mcm

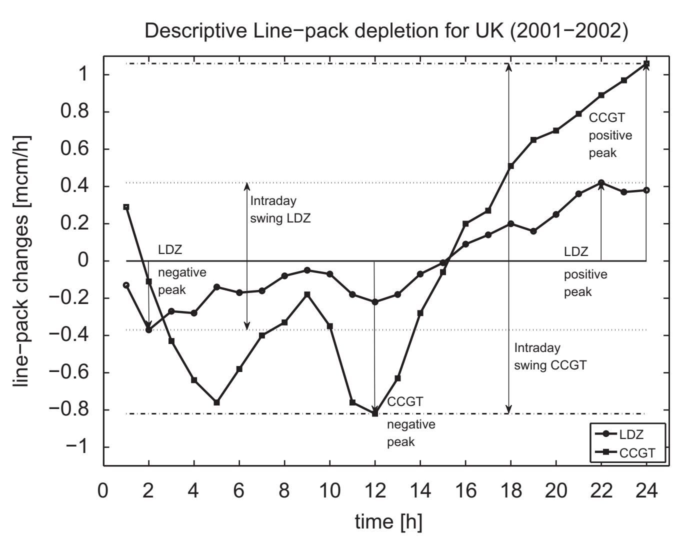

Fig. 4. Description of the maximum hourly line-pack depletion for local distribution zones (LDZ) and combined cycle gas turbines (CCGT) in UK (2001–2002) (author elaboration, data from Lapuerta, 2003 and OFGEM, 2003).

[4] The availability of an adequate market price for gas is an issue that has been discussed by ERGEG (2006, 2009). In the argumentation a proper gas price is assumed to be present to show that even in that case line-pack flexibility is treated inadequately.

for LDZ. As the UK balancing charges are based on gas market prices with a daily reference period, it is clear that the LDZ consumers will pay more for their balancing services, due to the flexibility needs of the CCGTs, despite the LDZ not having contributed to the greater costs for the system.

3.4. Conclusion on the value and costs of line-pack flexibility: ex ante balancing vs. ex post balancing

Line-pack flexibility, as argued above, is a pivotal element in balancing gas networks. In many countries it is the network operator's main tool to perform physical balancing. Implicitly, an imbalance becomes a storage service contract based on line-pack flexibility between the shipper and the system operator. So, with the current balancing framework in mind, the shipper makes a trade-off between *ex ante* balancing and *ex post* balancing. *Ex ante* balancing means contracting a portfolio of flexibility instruments on the market before the imbalance occurs, whereas *ex post* balancing means that the shipper relies on the TSO balancing mechanism. If contracting flexibility is more expensive for the shipper than paying the balancing charges, the shipper will prefer the implicit pipeline storage contract. Consequently, the deployment costs of line-pack flexibility should be properly reflected in the imbalance charges in order to target the costs to the actual users of the storage services. As the true balancing cost for the TSO is related to the peak cumulative imbalance within the balancing period, balancing charges should preferably refer to back to peak cumulative imbalances.

In other words, the balancing rules, tariffs and charges in the European network should take into account the real costs of TSOs to provide transport flexibility. This cost reflection issue becomes even more urgent with the changing gas demand profile that is characterized by increasing intra-day volatility as a result of the interaction between the gas and the electricity industry. Nevertheless, in practice, the balancing charges and rules have not been reflecting the network costs, at least not in a transparent way. This is illustrated by the example of the French regulator, who states in its latest deliberation on transport tariffs (CRE, 2009b, p. 2) that "*the first conclusions of the study on the gas infrastructures' capacity to satisfy the electricity power stations' requirements for intra-daily flexibility show that GRTgaz ought to find new internal and external sources of flexibility. GRTgaz has indicated to the CRE that these new requests are likely to mean extra operational costs,* [which are] *not planned in the current tariff trajectory. The CRE is going to consider how to design a regulated offer of intra-daily flexibility for the users in question. Depending on the progress of this work and if the extra costs presented by the TSOs are confirmed, the CRE may make a new tariff proposal, after consulting with all of the players, in the course of* 2010."

4. The market distorting consequences of "imbalanced" balancing rules and tariffs

The choice between balancing *ex ante* or balancing *ex post* implies that line-pack flexibility not only affects the availability of transport capacity through the trade-off mechanism explained above, but it also affects the market for other flexibility tools and even the spot market.

Therefore, cost allocation and cost reflection are both cornerstones for dealing with line-pack flexibility. A discrepancy in the tariff for the pipeline flexibility service, bundled or unbundled with the transport service, in relation to its true costs has an impact on two parts of the gas industry: the regulated part (allocating costs regardless of the consumer preferences) and the potentially competitive part (building an uncompetitive product regardless of its real cost).

ERGEG (2007, p. 19) has stated: "Economically, the cost for balancing the transmission network should be made where balancing can be done the cheapest. In other words, the penalties should reflect the actual and efficient cost of balancing the system." Economic efficiency is only achieved if the balancing service is provided by whoever can produce the service at lowest costs. However, in a liberalized market the players' decisions are not centralized. Therefore, only if the prices/tariffs reflect the real costs, the players will make the right decisions, and the least expensive balancing tools will be developed.

If cash out charges and penalties are high enough, e.g. gas-fired power plants may rely less on the *ex post* balancing, and they may prefer to contract more *ex ante* balancing (flexibility in gas commodity contracts, spot contracts, underground storages, LNG storage, or demand side actions) or buy more network services to allow the revision of their nominations (e.g. hourly) in order to meet their obligations as well as to minimize their costs associated with balancing charges.

4.1. Distorting effect on the regulated infrastructures

Nowadays in the EU gas market, the pipeline flexibility is either unbundled or bundled with other transport services according to the balancing rules. Furthermore, it is subject to regulated prices according to the balancing tariffs, which are usually linked to a commodity price. As was shown earlier in this paper, these rules and tariffs need to take into account not only the commodity price, but also the actual balancing cost of the TSO. This cost is thus dependent on the infrastructure that has to be committed to flexibility in order to cover the peak cumulative imbalance within the balancing period. Otherwise perverse incentives can be spread to the transport market and flexibility market. Summarizing, the TSO has to make a trade-off between offering time flexibility and selling transport capacity, and the shipper makes a trade-off between *ex ante* and *ex post* balancing. Clearly both trade-offs are interdependent.

The often applied pricing solution of a single regulated tariff for the bundled service is not cost reflective (the capacity commitment to the buffer function is not taken into account) and results in the earlier identified problem that all network users end up paying for the network flexibility needs caused by a specific group of users. The bundled service tariff is not only inefficient, but it prevents the provision of clear market signals for investment in transport services.

4.2. Distortion of the competitive markets

According to the International Energy Agency (IEA, 2002), liberalized gas markets rely on both new market mechanisms and traditional flexibility tools, meaning supply and demand adjustments and storage mechanisms, to match demand and supply over different time horizons. In the same report, the IEA stresses that flexibility is an absolute requirement for the efficient functioning of the gas market. Table 3 provides an overview of flexibility tools that can be used for balancing in different EU countries. Line-pack flexibility and storage are available in almost all countries. However, the availability of a tool does not imply its actual application for balancing.

The choice for the most efficient tool should be based on the tool's economic costs and benefits and not on the balancing rules without any economic justification. This unjustified obligation to balance is happening in Italy with storage, in Spain with LNG in most (if not all) EU countries with line-pack flexibility. The misallocation of network flexibility does not only provide wrong incentives in the transport service as discussed above, but also in

Table 3
Indicative role of different source of flexibility for system balancing (KEMA, 2009).

	Line-pack	Production	Storage	LNG	Import
Austria	X		X		X
Belgium	X		X	X	X
Denmark	X	X	X		
France	X		X	X	
Finland	X		X		
Germany	X	X	X		X
Greece	X			X	
Ireland	X		X		
Italy	X		X		
Luxembourg	X				
Netherlands	X	X	X	X	
Portugal	X		X	X	
Spain	X		X	X	
Sweden	X		X		X
United Kingdom	X	X	X	X	

the other segments of the gas industry that are able to deliver short term flexibility: the spot market and the flexibility market.

4.2.1. *The spot market*

According to the IEA (2002), market mechanisms are still the common flexibility providers in most product markets. In the European gas sector, however, complete reliance on only the gas commodity market mechanism for the balancing of demand and supply has not yet been applied because it has high social costs. These social costs can be explained by the analysis of the transaction costs along the industry value chain or by looking at the small price elasticity of demand and supply.

In the literature, it has been underlined many times that various parts of the gas industry chain are subject to high asset specificities, which economically implies that the transaction costs of market coordination are increasing and that the market players are driven to other mechanisms to coordinate the supply of services (Codognet, 2006; Codognet and Glachant, 2006; Creti, 2009; Glachant and Hallack, 2009; Masten and Crocker, 1985; Mulherin, 1986; Spanjer, 2009; von Hirschhausen and Neumann, 2008).

The small price elasticity of supply and demand impedes the market price to achieve the equilibrium where the cost of production would be equal to the value of demand, at least in the short term. The European Commission (2009) reported that the demand elasticity is dependent on the consumer category and the availability of multi-fuel installations. Furthermore, Stern (2009) has demonstrated that even the demand of the consumer category with the biggest elasticity has not been able to respond according to expectations to the price increase in the last years in Europe. Therefore, it can be assumed that the *ex ante* gas market is not a sufficient tool to balance supply and demand in the short term. However, the inadequate pricing of *ex post* balancing possibly even contributes to the low liquidity in the spot market, if the shipper is better off at trading within the balancing mechanism framework than on the spot market. On the supply side, domestic production (e.g. in Norway, the UK and the Netherlands) is the main source of flexibility as has been shown by Lapuerta (2003) and Creti (2009). Most of the EU countries have no or very little domestic gas. Therefore, production cannot be considered a fundamental tool for gas system balancing.

The gas imported from distant sources through very long pipelines can bring some flexibility (European Commission DG Transport and Energy, 2008); however, the cost of this flexibility is subject to the same trade-off that has been described earlier in this paper. Moreover, the cost of decreased transport capacity in long distance pipelines may have even higher opportunity costs.

LNG is claimed to be another major source of flexibility allowing a decrease of contract rigidity as demonstrated by Neuhoff and von Hirschhausen (2005) and allowing more arbitrage as explained by Zhuravleva (2009). However, LNG is still small business in comparison to pipeline gas and it remains a costly tool, which is an argument that will be taken into consideration at the time of a flexibility investment decision.

4.2.2. *The flexibility market: high frequency storage*

Pipeline storage differs from traditional underground storage, which usually has a business model with a longer term profile and is dedicated mainly to the seasonal needs. Examples of traditional storages are depleted gas fields or aquifers. These underground storages typically have lower injection and withdrawal rates and large storage capacities allowing only a few cycles (meaning a full loading and unloading of the facility) per year; whereas pipeline storage has a daily cycle and very high deliverability, but is limited in working volume (Clingendael, 2006).

Pipeline storage answers the need for higher frequency balancing, as explained by the European Commission's DG Transport and Energy (2008, p. 69): "*High-frequency optimisation, i.e. optimisation on a daily basis can be regarded as fine-tuning of the stock level. Short term optimisation allows gas market agents to utilise the price differences that exist on a day-to-day basis.*" Still according to the same report of DG TREN, the salt caverns and LNG peak-shaving facilities are the most flexible types of storage because they have higher withdrawal and injection rates compared to aquifers and abandoned fields, but also higher costs. The real cost of a specific storage facility is case dependent.

Therefore, pipeline storage is in competition with these higher frequency storage facilities (underground with high deliverability and LNG). The offer of pipeline flexibility is basically a regulated decision, whereas the demand for it depends on the "tariff" to use this flexibility service and on the costs of the other flexibility sources. In order to have an efficient mechanism of storage selection, especially concerning the short term storage, the tariffs should reflect the costs of line-pack flexibility. If the line-pack storage is free to shippers in the short term, they will not have any interest to contract other kinds of storage that can be used with the relevant frequency. In other words, the potentially competitive storage market can be distorted because the actual line-pack flexibility costs are carried by the transport network and are socialized by means of transport and balancing tariffs, meaning that shippers with a flatter profile subsidize shippers with more volatile consumers (Costello, 2006).

5. Conclusions and recommendations

As shown in this paper, line-pack flexibility is an important balancing tool with an economic value and cost. This cost has been demonstrated to relate to the amount of capacity that has to be committed to flexibility. And this amount is dependent on the swing between peak cumulative imbalances throughout the balancing period. However, current gas regulation does not properly take into account these actual costs of line-pack flexibility. The subsequent inadequate regulation results in market distortions in the regulated transport market, the competitive spot gas market and the market for *ex ante* flexibility, which is at least potentially competitive. By not considering the actual costs of line-pack flexibility, policy makers neglect the market-impeding role of a badly regulated pipeline flexibility service in the choice of the shipper between *ex ante* and *ex post* balancing.

In other words, the balancing service offered by the line-pack flexibility is a valued service. If its cost is socialized, especially by means of the transport tariffs, there is a tendency to have an "over demand" of line-pack flexibility and an "under demand" of transport, because the regulated price passes on the costs to all consumers and not to the actual users of the flexibility. If the flexibility demand is heterogeneous this situation becomes even worse because the flat consumers will subsidize the transport network required by unbalanced shippers.

The market-based solution exists in taking away line-pack flexibility from the regulated system operator and including it in the *ex ante* flexibility market. The price for line-pack flexibility would be set by the marginal unit of flexibility contracted by the market players in a way comparable to the merit curve that is used for unit commitment in electricity generation systems.

As shown, the gas dynamics behind line-pack flexibility make the complete separation from pipeline transport and pipeline flexibility unlikely. In that case we recommend a different way of calculating a regulated tariff. Because several gas system and market aspects have to be taken into account, the correct pricing of line-pack flexibility, which is a second product offered by the monopoly gas network, is non-trivial. The traditional methodologies to set tariffs for monopoly infrastructures cannot be applied, due to the flexibility product being actually part of an oligopoly market. In this context, the trade-offs and related opportunity costs presented in this paper constitute a framework for policy makers to take into account the costs of line-pack flexibility in the overall network system. Moreover, we recommend that the price of line-pack in a balancing mechanism should refer to the swing between the peak and dip cumulative imbalance over the balancing period.

We further recommend that the regulated decision to offer more or less line-pack flexibility should be based on the real network costs and benefits. As there is a trade-off for the TSO between offering transport capacity and offering time flexibility, an additional unit of flexibility comes at the cost of decreased available transport capacity. This cost can be measured by comparing the costs of transport capacity availability with more or less bundled flexibility.

As the evidence in this paper illustrates, further research is required to develop a deeper understanding of the complex interactions between the transport flexibility, the flexibility market, meaning the short term storage, the short term contracts and the flexibility clauses of the long term contracts and the gas spot market. The calculation of the identified inefficiencies in practice would give a better insight into the money on the table. This exercise is beyond the scope of this paper, though.

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Appendix A. Balancing mechanism: European practice

The majority of EU 15 countries[5] formally apply a balancing period of one day, even if the effective balancing frequency is higher due to the imposition of penalties for imbalances over shorter intervals. Such penalties are applied at an hourly frequency in Belgium, the Netherlands,[6] Luxembourg and Germany, or for peak cumulative deviations over the balancing period (Belgium, the Netherlands and Luxembourg), as is illustrated in Table A1. The tolerances for hourly incentives allow "mixed mechanisms" to be defined that are less restrictive than purely hourly balancing, without giving total freedom to the shipper for 24 h in a daily mechanism.

In Italy, Portugal and Spain penalties do not relate to within-day balancing restrictions, but rather depend on the use of other flexibility instruments (e.g. storage). In these balancing mechanisms, the system operator has access to the flexibility instruments of the shipper, who is required to buy a certain amount of flexibility if he wants to ship gas. The purely hourly based balancing in Austria is unique in Europe. Moreover, the Austrian TSO relies on an auctioning mechanism to obtain balancing flexibility.

The determination of balancing charges, i.e. cash out charges and penalties, also varies largely between the EU countries (Table A2). As market based mechanisms play only a minor role in the short term procurement of balancing gas. Non-market based methods continue to represent the main, and often even the exclusive form of procurement in most countries. Moreover, even when market based methods are used, they are mostly based on medium term horizon commodity products.

Italy and Spain provide interesting examples as their balancing charges are based on charges for other flexibility instruments. The former establishes balancing charges in line with tariffs for underground storage, which is a highly important flexibility instrument in the Italian gas system. Spain on the other hand, aligns its balancing charges to the LNG storage tariffs because LNG makes up the main flexibility tool in the Spanish gas system. These two examples also show the possible trade-off role of line-pack

Table A1
Use of cash out charges and penalties for different balancing frequencies in EU 15 (author elaboration, data from KEMA, 2009).

	Penalty (outside tolerance)	Cash out (outside tolerance)	Full cash out
Evergreen	ES, IT, PT	FR	
Monthly			GR
Daily		FR, GR	BE, DE, DK, UK, IE, LU, NL, SE
Cumulative (within-day)	BE, LU, NL		
Hourly	BE, DE, LU, NL		AT

Cash out: payments between TSO and shipper which financially return the imbalance to zero.
Penalty: payment made by the shipper to the TSO when tolerance restrictions are violated.
Evergreen: all imbalances are settled in kind.

Table A2
Determination of cash-out prices and penalty charges EU 15 (author elaboration, data from KEMA, 2009).

	Administrated	Indexed	Market based	
			Average cost	Marginal cost
1 Price	IT	IE, NL	AT, UK, FR, SE	
2 Price	ES, GR	BE, DE, DK, FR, LU		UK, SE
Penalties and other charges	GR	AT, BE, NL, PT		

[5] EU 15: Belgium, the Netherlands, G.D. Luxemburg, Germany, France, Italy, UK, Ireland, Denmark, Greece, Spain, Portugal, Austria, Sweden and Finland (Finland was not included in the data from KEMA, 2009).

[6] Note that the Netherlands are in the process of implementing a new market based balancing mechanism, and that the data in the table is based on the mechanism that was operational in 2008.

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Table A3
New services of balancing offered by TSOs (AT, BE, DE, NL) (author elaboration, data from Lapuerta, 2003 and IEA, 2002).

	Available flexibility services
Austria	Individual flexibility management contracts
Belgium	Rate flexibility (capacity delivered)
	Volume flexibility (allows to accumulate imbalances)
Germany	Extended balancing (m^3/h/yr)
	Balancing management
Netherlands	Tolerance capacity service (m^3/h/yr)

flexibility (*ex post* balancing) against *ex ante* balancing instruments such as underground storage and LNG.

Most other prices in Table A2 reflect gas prices, either index based or spot market based. Such pricing supposes that gas trade is the main instrument to balance the gas system and its cost is passed on through the balancing charges.

The UK and Sweden should also be highlighted regarding their application of marginal prices. Even if the spread between the marginal price to buy and the marginal price to sell is not a formal penalty, it causes additional costs to imbalances shippers. Indeed, an end-of-day unbalanced shipper would be cashed out as if he had traded in the gas market at the worst rate possible. So, he pays the higher price to buy deficit gas and receives the lower price to sell excess gas. This spread incentivizes shippers to balance *ex ante* in the regular within-day spot market (e.g. OCM for UK).

Finally, Table A3 lists some examples of balancing services that have been proposed by system operators to shippers in order for the latter to accommodate their balancing needs. These services can be a way for the TSO to sell line-pack flexibility and other flexibility tools, unbundled from the transport service. The unbundling allows the costs between shippers to be allocated in a more correct way.

Strikingly, only TSOs that have within-day restrictions in the balancing mechanism offer within-day flexibility services. As underlined throughout the paper, the basic daily balancing mechanism offers “free” (meaning socialized in balancing tariffs) within-day flexibility to shippers. These shippers in turn have no interest in buying or developing other kinds of within-day flexibility.

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