REFGOV

Reflexive Governance in the Public Interest

Institutional Frames of Markets

Electricity Transmission Module:
ideal and actual transmission arrangements.

ADIS – University of Paris Sud XI (France)

Working paper series : REFGOV-IFM-8

Annexe 7: Electricity Transmission Module:

ideal and actual transmission arrangements

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Abstract

As far as the management of the power flows on a transmission network is concerned by externalities, Transmission and System Operators (TSO) are externalities market designers, and so can be studied thanks to a modular analysis grounded on Wilson [2002], Brunekreeft *et al.* [2005] and Glachant *et al.* [2005]. And as institutional entities, the solutions of each module they implemented are constrained by compatibilities requirements. Our resarch develops such a framework and such an argumentation. Then, although the economic theory specifies a unique arrangement to reach efficiency, we can understand why there is such a diversity of TSO arrangements and of heterogeneous results among TSOs through the comparison between an ideal first- best TSO and two reference TSOs, PJM and NGC, with quite opposite features.

I. Introduction

As far as the management of power flows are concerned, a Transmission and System Operator (TSO) must achieve three main missions: the short-run externalities management, the long-term management and development of the network (Brunekreeft *et al.* [2005]) and coordination with neighbouring TSOs to deal with border effects (Glachant *et al.* [2005]). Economists and engineers know quiet well how to manage efficiently a power transmission network and how to provide network signals that involve an efficient reaction of the network users. Implementations of short-run efficient signals were proposed (Schweppe *et al.* [1988], Caramanis *et al.* [1982]) and were applied on several power markets such as Argentina, Chile, New Zealand or in some Northeast states of the USA or recommended on others (FERC [1999], EC [2004]). Smeers [2005] extend some of these implementations to the long-term signals despite theoretical difficulties. Meanwhile such network signals are already applied under a pragmatic way in a quite limited number of network areas. The regulation of a natural monopoly such as the transmission one always raises some issues. But at least what not to do to ensure an efficient development of the network is quite well known (Pérez-Arriaga *et al.* [1995], Green [2003]). The coordination between neighbouring Transmission and System Operators was studied and said to be quite easy at least for the short-run management of network externalities (Cadwalader *et al.* [1999], Marinescu *et al.* [2005]). Some coordination agreements are near implementation in the USA (MISO-PJM [2005], MISO-PJM-TVA [2005]).

Nonetheless, systems where at least one of efficient solutions mentioned above are applied are limited and several of these solutions are seldom implemented in a unique system. Moreover, implementing inefficient solutions does not mean implementing the worst ones and succeeding in the most awful results.

One can wonder why there is such a diversity of arrangements of Transmission and System Operators and such inhomogeneous results while the most efficient solutions are well known or at least widely conjectured. Rather than watching the operational implementations alone, one must deem that the TSO is evolving in an institutional context that constraints the feasible space in which it can rule the transmission network. There exist compatibility requirements on the one hand between the organisational structure of transmission and the management schemes applied on the network and on the other hand between the management schemes themselves.

An analysis framework following the same modular philosophy as Wilson [2002] is needed to understand these compatibility requirements between the missions of the TSOs. It surveys the implementations of operational missions of TSO (previously mentioned) by comparing them through their level of internalisation of externalities of power flows. It ignores issues related to balancing in general. The structure of governance of transmission is studied through the unbundling of the network and the possible conflicts of interests of the regulatory policies. It can then be applied on the modular framework to make some compatibility requirements emerge between missions of TSO.

In section II, we will argument the possibility of studying the TSO with such a modular analysis framework while surveying the possible solutions of implementations and analysing their internalisation of externalities without any prejudices of performances or compatibilities. In section III, the structure of governance of transmission will complete this framework and will introduce the compatibilities requirements between the operational modules under three axes of importance in the context of a wholesale power market. In section IV, an empirical study of two reference TSOs, PJM and NGC, with quite opposite features will be made thanks to our modular analysis framework. We will then be able of understanding why there are such heterogeneous results between TSOs.

II. A modular analysis framework

As market designers, TSOs can be characterised thanks to a common modular analysis framework similar to the one developed by Wilson [2002] to analyse power markets that would focus on the management of externalities of power flows. This common analysis framework presents the different solutions to implement the following modules that stand for the three main missions of TSOs: the short-run management of network externalities, the long-term development of the transmission network infrastructures (Brunekreeft *et al.* [2005]) and the management of border effects between control areas (Glachant *et al.* [2005]). The solutions of each module are differentiated thanks to the level of internalisation of externalities. These solutions are presented under the assumption that the TSO and the regulator are benevolent, efficient and well coordinated. It is then possible to design an ideal first best TSO by summing up the most efficient option of each module. Even if this arrangement cannot be reached in reality, it can be a benchmark for future comparisons of TSOs performances as for the management of power flows.

II.A. The short-run management of network externalities

The management of the short-run externalities on a power transmission network also called system operation is the first mission of a TSO as a network manager. It must indeed ensure a short-run local adequacy between generation and consumption while respecting the network constraints. Otherwise the system would collapse. Different solutions with various levels of integration between the system operation and the energy market are possible to fulfil this target.

The efficient share of a network as a scarce resource is a well-known and addressed issue in the restructured electricity industry. Caramanis *et al*. [1982] and Schweppe *et al.* [1988] demonstrate that an efficient constrained dispatch could be computed thanks to a nodal pricing system considering all the network externalities, that is to say congestions, voltage constraints and losses as constraints of the market clearing. A nodal pricing gives an energy price per node indicating where it is preferable to generate or to consume one more megawatt taking into account both network losses and network limitations. The price differential between nodes linked to the externalities generates a merchandise surplus for the TSO, also called congestion rent in the DC lossless approximation[1]. The network limitations prevent the optimal dispatching from reaching the maximum of social surplus free of externalities. It results a deadweight loss also called congestion cost in the DC lossless approximation. For instance, congestion cost and congestion rent can be easily exemplified in a well-known two nodes example (see Figure 1) and can be more generally calculated (Schweppe *et al.* [1988]).

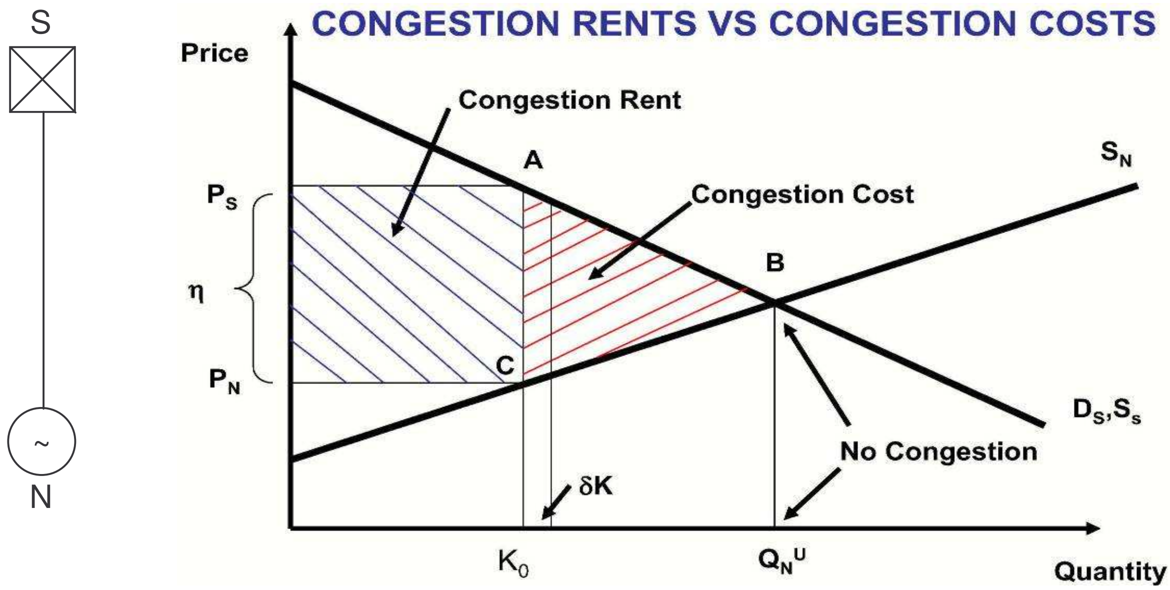

Figure 1 Graphical representation of congestion rent

on a two nodes network (Joskow [2005a])

It is possible to separate the externalities management from the energy market. This scheme is called the redispatch scheme. In this case, the energy market assumes there is no network loss or constraint and the network externalities are managed by the TSO after the market clearing. The subsequent redispatch cost is born by the TSO for the short-term operation. It is generally socialised to the long-term in the use of the network tariff. Only the redispatched units know that there are network constraints.

Depending on the externalities considered, different management schemes can be used. For instance, both the congestions and the losses can be included in the nodal pricing while the voltage constraints are socialised. Similarly, different management schemes can be used on a same externality depending on its amplitude. For instance, zonal pricing mixes the two previous schemes (Bjørndal-Jørnsten [2001], Ehrenmann-Smeers [2005]). The main congestions are treated thanks to nodal pricing on an aggregated zonal network while the temporary congestions are managed thanks to redispatch and their costs are socialised as before.

To conclude, the different solutions to manage externalities on a power transmission network can be summed up as follow:

[1] The more used approximation, namely DC approximation consists in considering only the real power and in approximating the behaviour of the network to be linear. In this case, only the congestions constraint the nodal pricing.

Chart 1 Classification of the externalities management schemes by level of integration between the system opertion and the energy market and the level of socialisation of the cost of system operation

Externalities management schemes	Level of integration between the system operation and the energy market	Level of socialisation of the cost of system operation
Nodal pricing	High	Low
Zonal pricing	Medium	Medium
Redispatch	Low	High

II.B.The long-term development of the transmission network

The long-term development of the transmission network as the second mission of the TSO as a network manager results from the system operation. The short-run management of the network externalities informs the TSO and the network users on the network constraints. Despite these constraints, the TSO must ensure a local adequacy between consumption and generation while allowing for an efficient joint investment of the network and of the network users. Consequently, this mission of the TSO is a two-part one. The TSO that is assumed to be benevolent will invest to make the social cost decrease. Moreover, the short-run signals when they are public data are necessary but never sufficient to guide the location of the network users. They must be completed by long-term locational signals through network tariffs (Green [2003]). Besides, the merchandise surplus never recovers the whole cost of transmission (Pérez-Arriaga *et al.* [2005]). These network tariffs also complete the TSO's revenues and allow to recover its investments costs (Pérez-Arriaga & Smeers [2003]). Different methods that are more or less capital intensive are possible to define this tariff and to allocate the network charges (Hiroux [2005]).

The most capital-intensive method to allocate the transmission connection charges is the deep cost allocation method. The deep cost allocation means that the cost of all new network assets is attributed to the beneficiaries, whatever the reason is: an increase in consumption, a new connection, an upgrade of generation assets, etc… The network assets considered are as much the connection assets as the upgrades and improvements required in the core of the transmission network. This method may be controversial because of the individual allocation of costs associated to indivisibilities. But recent theoretical developments have made it possible to calculate marginal participation even in the presence of indivisibilities. Smeers [2005] applied them to calculate a true marginal network tariff but it is still far from practice.

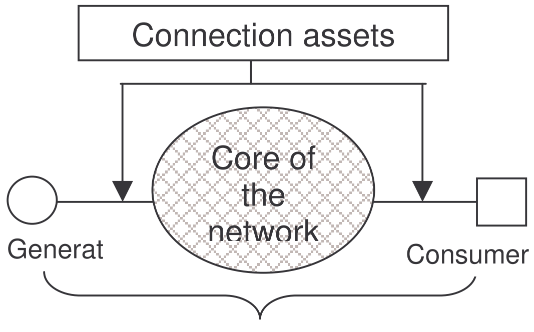

Figure 1 Deep cost allocation method

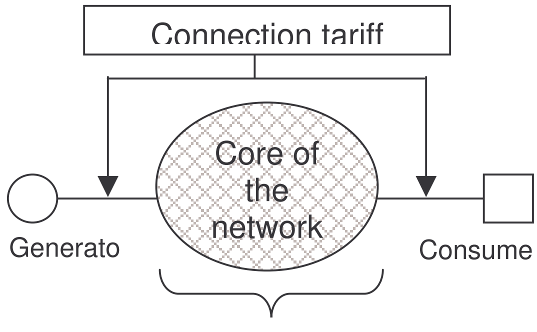

Figure 2 Shallow cost allocation method

To the contrary, under the shallow cost allocation method, the beneficiaries pay only the «shallow» part of the network, that is to say the direct connection assets through a connection tariff. The upgrades and improvements of the core of the network are

socialised among all the network users through a use of the system tariff[2]. A third hybrid method mixes the two allocation methods. The connection tariff is the same one as in a shallow allocation method but the use of the network tariffs are differentiated depending on the zone where the connection is required.
To conclude, the different solutions to allocate network charges can be classified as follow.

Chart 2 Classification of allocation methods of costs of network infrastructures by its repartition between the connection and the use of system tariffs

Allocation method	**Connection tariff = x% of the network revenue**	**Use of the system tariff = (1-x)% of the network revenue**
Deep cost	100	0
Shallow cost	~0	~100
Hybrid or zonal	0<x<100	0<(1-x)<100

Following the response of the network users to the short-run and long-term locational signals and the evolution of the load and generation patterns, the benevolent TSO arbitrates between the social costs noticed from the short-run operation and anticipated from the connection requests and the costs of network investments. Indeed, economies of scales and scope and lumpiness of lines capacities make transmission a natural monopoly. The transmission investments decisions must so be centralised rather than decentralised and using a marginal rationale to be efficient (Joskow-Tirole [2005]).

II.C. The coordination of TSOs

Because of the meshed nature of the transmission network, TSOs must be coordinated to internalise in their systems external loop flows and border effects[3]. They can then optimally use the whole power resources and ease the arbitrages and the fusion of markets. The coordination between TSOs includes the coordination of both the externalities management schemes and the long-term development of the networks.
There exists two main ways of coordinating adjacent systems in the context of a power market: standardising them or combining them (Glachant *et al.* [2005]). The coordination by standardisation implies that each TSO must choose the same solution for the externalities management scheme and for the long-term development of network and communicate each other a minimal set of information on the state of its network and market (see Cadwalader *et al.* [1999] for the coordination of externalities management schemes). The coordination by combination needs the implementation of standard inter-TSO footbridges to allow the coexistence of different individual schemes.
Without considering the cost of implementing coordination, standardisation achieves full efficiency while combination is only a second-best. Nevertheless, depending on the cost of implementing coordination compared to the benefit of the reached coordination, the coordination by combination or no coordination may be more efficient (Costello [2001]).
The need for coordination between neighbouring control areas and the efficient type of coordination greatly depend on the network configuration and topology between these areas. The more highly meshed the links between control areas and internal networks are, the more efficient the coordination may be to deal with border effects (Costello [2001]).
To conclude, the different solutions of coordination to manage order effects on neighbouring power control areas can be summed up as follow.

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[2] The definition of the use of the system tariff may vary a lot depending on the network and market rules. Mainly, it covers the costs of providing and maintaining transmission assets and balancing the system (system operation, ancillary services, losses and congestions when they are socialised).
[3] Also called spillover effects (Costello [2001]).

Chart 3 Classification of coordination solutions between neighbouring TSOs by level of internalisation of border effects

Coordination between neighbouring TSOs	Level of internalisation of border effects
No coordination	Low
By combination	Medium
By standardisation	High

II.D. An ideal first-best TSO

A first-best TSO will be made of the efficient choice for all the modules of the common analysis framework. Such a TSO must send economic signals to the network users to ensure an efficient use of the network. It must also be regulated in such a way that the network is efficiently develop. And this TSO must be coordinated with its neighbours to ensure the management of the border effects between the systems.

The short-run externalities are managed thanks to a nodal pricing to ensure an efficient dispatch and an efficient allocation of the scarce transmission capacities (Schweppe *et al.* [1988]).

The long-term objective of a well-designed and -incentivised TSO is to develop the network in order to maximise the social surplus. Other things equal, this is equivalent to minimise the sum of the cost of externalities, the operation and maintenance (O&M) cost and the investment cost (Pérez-Arriaga - Smeers [2003]). In order to invest efficiently, the TSO must then determine the deadweight loss of the externalities and must be regulated in order to decrease this social cost compared to the network investments costs. In order to apply such a regulation of the system operation, a first-best TSO must be a heavy one to be penalised by its regulator without danger for its survival.

Network tariffs are deep cost ones to ensure an efficient location of the network users despite the externalities and indivisibilities of the investments (Hiroux [2005], Smeers [2005]). However, publication of accommodation capacities that is to say the nodal quantity of new generation or consumption that can be connected without creating new congestion should make this allocation method more auditable to the network users.

Since the nodal methods such as the nodal pricing and the deep cost allocation are the more appropriated to internalise network externalities, they are also the more appropriated to internalise the border effects over several control areas (Glachant *et al.* [2005]) if the neighbouring control areas communicate the required set of information and data (see Cadwalader *et al.* [1999] for the coordination of externalities management schemes).

To conclude, an ideal first best TSO must fulfil its mission thanks to the following implementation:

Chart 4 Constitution of an ideal first best TSO

Missions of the TSO as an externalities market designer	Implementation to reach an ideal first best TSO
Externalities management scheme	Nodal pricing
Network investments	Centralised by TSO
Allocation method	Deep cost + accommodation capacities
Coordination with neighbouring TSOs	By Standardisation

III. Compatibility of the modules of the network management

In our common modular analysis framework, we have presented various choices for each modules of the network management without presupposing any goal of efficiency or any incompatibility between modules under the assumption that the TSO and the regulator are benevolent, efficient and well coordinated. However, if the regulator is more or less light-handed or if its policy faces conflicts of interests, the first-best TSO cannot be reached because options of some modules can then be incompatible between themselves or defined in advance. The organisation of transmission indeed supports these operational modules by relaxing the last assumption about the TSO and the regulator and by explaining the interactions between the TSO and the rest of the power supply chain.

We will show that the structure of governance of the transmission network imposes some compatibility constraints between the constituting TSO modules under the achievement of key goals. Then we will discuss three goals of importance in the context of a wholesale power market. First, efficient locational signals have an increasing importance to allow coordination between the network users and the accommodation capacity in spite of the unbundling of the network. Second, defining an easily regulated TSO is of importance to ensure an efficient development of the network. Finally, an inter-TSO scheme must allow for an efficient use of the meshed nature of the transmission network.

III.A. The structure of governance of the transmission network

The modules presented above create operational relationships between the TSOs and the rest of the power supply chain. The relationship between the network users and the TSO was quite obvious. The relationship between the TSO and the regulatory authorities was mentioned because the TSO can face an opportunism issue in choosing the externalities management schemes and in investing. The System Operator (SO) and the Transmission Owners (TO) were supposed to be part of the same entity but it may not be the case. These relationships are underlain by industrial and institutional links where the organisational structure of transmission is of importance. First, we will explicit the relationship between the system operator and the transmission owners thanks to the different ways of unbundling the network. Secondly, we will explore the impact of the network unbundling on its relationships with the rest of the power supply chain. It encompasses not only a part of the market design but also its regulation without forgetting the influence of conflicts of interests of regulator and political economy.

In the context of a wholesale power market, an open and non-discriminatory access to the network is necessary. The easiest way to ensure such an access to the network is then to make the network independent from the other activities of the power supply chain.

Unbundling system operation and transmission ownership from the other activity of the power supply chain is the most obvious way of ensuring such independence. But this divestiture may be tricky to impose since the network is a moneymaking asset base.

The unbundling of the network can be influenced by other constraints, mainly technical ones. For instance, the USA power network is balkanised with around 400 utilities and 100 control areas (Pérez-Arriaga - Olmos [2005]). In this context, the loop flows are numerous. And the market is making the seams issues more and more critical for the network security. Transmission Load Relief, a procedure to relieve congestions on interconnector between adjacent control areas thanks to the interruption of bilateral contracts crossing it is indeed more and more often activated (Joskow [2005b]). The unbundling of both the operation and the ownership of the network from the rest of the power supply chain may have not been sufficient to solve them. The solution adopted in the USA is then to divest only the System Operator functions and to merge them in a third party, an Independent SO or a Regional Transmission Organisation (ISO/RTO). It implies little change in the industrial structure. Indeed, this solution manages border effects through horizontal integration (Costello [2001], PJM [2004b]). For the rest of this paper, heavy TSO will refer to TSO that owns part or the whole network it operates while asset-poor SO will refer to TSO that owns no network asset and TSO will be used as a generic term referring without distinction to both cases.

Eventually, the wideness of seams issues and the possibilities of modification of the industrial structure of the power supply chain dictate the way the network is unbundled. It has consequences on the governance and regulation of the transmission network as a natural monopoly. Various classifications of governance of TSOs with different levels of details are already available (Barker *et al*. [1997], O'Neill *et al*. [1996], Boyce-Hallis [2005]). But, we will only focus on the impact of the governance of the TSO on its regulation and on market design.

The governance of asset-poor SO is a regulatory compromise with the industrial structure. Since regulatory incentives are hard to impose on an asset-poor SO, a self-regulated not-for-profit organisation can be an alternative to a for-profit one that is incentivised only on a part of the social cost of network externalities (Barker *et al.* [1997]) and is still to be implemented. Indeed, the fair participation of network users in such organisation should ensure its independence and its *de facto* regulation if there is no risk of collusion or capture of the organisation by a group of interests.

On the contrary, the bundling of Transmission Owners and System Operator increases information asymmetry for the regulator (Boyce-Hallis [2005]). But the integration of the system operation and of the transmission ownership allows regulator[4] to threaten TSO of financial penalties if its regulatory contract is not respected. It is without severe consequences for the TSO's survival even if the TSO only owns a part of the transmission of its control area thanks to its tariffs revenues. Hence, the bundling of the System Operation and the Transmission Ownership may eventually ensure a better control of the network management and a more coherent evaluation of the needs of new investments.

Besides its role of controller of the costs of the TSO, the regulator may want to achieve other goals that may be paradoxical with the achievement of an efficient market, that is to say made of efficient implementations of the previous modules. It may also have difficulties in fulfilling its agenda because of political economy and the distributional impact of the solutions of the operational modules (Pérez [2002 and 2004]).

As System Operator, a TSO is also the main architect of the market design as far as the network externalities are concerned. The market participants are not stakeholders in the case of a heavy TSO. Thus, they may be considered "only" as customers. Therefore, the building of the market design of network externalities may be influenced by the heavy TSO also defending its financial position. Moreover, in the construction of a regional market, asset-poor SOs are less subject to incompatibilities of market designs since they are themselves regional coordinators and face little financial stake.

To conclude, the governance of TSOs is a compromise between the costs control and the market design and coordination. The capital assets of a heavy TSO allow for a heavy-handed regulation but may interfere in market design and the coordination

[4] We only consider investor-owned or state-owned transmission because customer-owned transmission organisations are far too rare.

over various control areas and vice-versa an asset-poor SO may be easy to coordinate but harder to regulate.

III.B. Compatibility between the externalities management scheme and the network development in term of regulation and costs control

The regulator's ability in controlling the TSO and the governance of the TSO vary with reforms. Therefore, the choice of the externalities management scheme must be carefully chosen for the TSO to be easily regulated despite the regulator's power and it must be compatible with its governance. Indeed, the TSO naturally has different abilities depending on its governance and faces different incitement in managing and investing depending on the externalities management scheme. Moreover, the robustness of the externalities management schemes to market power must be evaluated since market power can mislead the network investment decision.

Indeed, as regards the evaluation of the need for network investments, each scheme can be subject to a more or less wild use of local market power by reliability-must-run generators. Such behaviour can lead to an overestimation of the need for investments (Joskow-Tirole [2005]). The redispatch scheme is said to be more sensitive to these issues because the congestion cost is socialised (Harvey-Hogan [2000]). Since users of the network don't bear the cost of the externalities, they may game it and significantly increase congestion cost (Green [2004]).

Despite the nodal pricing scheme being efficient in inciting the dispatch of the network users and partly their locations, it gives counter-incentive signals for the TSO to trigger network investments. Indeed, a profit-maximising TSO basically compares the modification of the congestion rent following the investments with the investment costs and the O&M costs. Then, this scheme could entice a profit maximising TSO to make a congestion last in order to maintain the congestion rent (Pérez-Arriaga *et al.* [1995]) or deliberately to mishandle the O&M schedule (Joskow-Tirole [2005]). Similarly, under a zonal pricing, the TSO faces an opportunism issue related to the collection of interzonal congestion rent while minimising the intrazonal congestion cost (Glachant-Pignon [2005]). Therefore, a TSO that manages network externalities thanks to nodal pricing will require a more demanding regulatory scheme for the regulator to be sure the TSO's objective of maximising profit is compatible with the objective of maximising the social surplus.

On the contrary, a congestion management scheme based on redispatch may be inefficient in dealing with short-run externalities but the TSO directly faces the congestion cost from the short-run operation of the network and anticipates it from the connection requests. A profit-maximising TSO compares these congestion costs with the investment costs and the O&M costs. As mentioned in 0, it approximates a social welfare maximisation since the congestion cost is a proxy of the social cost of the externalities (Pérez-Arriaga – Smeers [2003]). The regulator can then easily check for the planning of investment for economic reasons to be compatible with the congestion costs. Nevertheless, the rules of the balancing market must ensure a tight management of the congestion cost to avoid Inc and Dec game and issues raised by local market power.

Whatever the market design chosen, a solution could be to incentivise the TSO on the deadweight loss. As a result, the regulator is sure to have an open access to this information. It is relevant since the TSO can access more related information than anybody else regarding this topic (Newbery *et al.* [2004]). Besides, it may solve a part of the market power issue, the local one. However, one must keep in mind that such an incentive scheme requires the TSO to be a heavy one for the penalty not to jeopardize its financial survival. Therefore, if the TSO is a self-regulated not-for-profit asset-poor SO without financial interests, a nodal pricing is a better option, which does not prevent it from calculating the congestion cost from the market bids and offers in order to invest efficiently.

III.C. A very limited compatibility of the externalities management scheme and of the network development in term of locational signals

The network investments are capital-intensive ones. Therefore, the choice of allocating its charges is determinant for the appreciation of the network limitations and opportunities in the long-term behaviours of the network users. As a result, the efficient location of network users and the solution of the related module may be contradictory with other goals. For instance, the allocation method of the network charges can be a shallow one to promote network demanding generation technologies such as wind farms, to ease the connection of new entrants in a new market area or to maintain a standardisation of tariffs in the TSO control area. The externalities management scheme faces analogous issues of compatibility as demonstrated above and is nevertheless insufficient in emitting long-term locational signals.

As regards the participation of the network externalities management scheme in the incentive of the location of the network users, the nodal pricing is indeed more predisposed to the incitement since the nodal prices are *de facto* public data, whereas the redispatch scheme only provides price information to the redispatched units and so requires the publication of a kind of a public nodal dispatch. However, nodal prices only provide a local value of the network constraints, do not measure the impact of a new investment on the other nodes and may not be efficient as long-term locational signals. Even property rights such as Financial Transmission Rights (FTRs) (Hogan [1992]) are subject to such limitations unless the investor receives the algebraic set of created FTRs (Bushnell-Stoft [1997]).

Nevertheless, nodal pricing does not provide enough revenues for the network cost recovery because of economies of scale exacerbated by indivisibilities in network investments (Pérez-Arriaga *et al.* [1995]). Moreover, all the externalities are not internalised in nodal prices, for instance network security or resource adequacy. Indeed, all these solutions cannot deal with either the network externalities of the investments of generation and transmission or the indivisibilities of the network investments (Joskow-Tirole [2005], Smeers [2005]).

Therefore, a locational network tariff is necessary to deal with the locational indivisibilities of the network and the externalities of the investments. Only a deep cost tariff can support such requirements but under the condition of full discrimination: two network users connected to the same node can have different connection costs because the connection of the last one has triggered new network investments for instance. A shallow cost allocation method only incites the network users to be near the core of the network. The hybrid method is an intermediary solution and consists in keeping the non-discriminatory approach of socialisation and in incentivising the connection area of new users. A problem remains in what the intensity of the economic signal sent through this locational differentiated tariff must be.

As regards the availability of the locational incentive signal, the network users can have to pay to know if they can connect and how much it costs since network studies are very costly. In the case of shallow or hybrid allocation method, this information is generally cheap. On the contrary, the deep cost information is costly and only provided to connection requests. The availability of accommodation capacities can make this cost allocation method more auditable to the network users. However, such information can be hard to compute since the accommodation capacities of nodes are interdependent and may vary from connection request to connection request. If nodal accommodation capacities are available, they cannot be simultaneously feasible.

To conclude, the choice for the locational signals is quite limited. Whatever the choice of the externalities management scheme, a tariff is needed to send a locational signal that internalise the indivisibilities and the externalities of the investments. The provision of accommodation capacities ensures the allocation method to be more auditable to the network users. However these price and volume signals may have a limited impact on the location of the network users since the network users that can choose their location (producers and large consumers) are also constrained by their primary resources such as water, wind, coal, etc…

III.D. Compatibility between TSOs for coordination

We demonstrated that organisational structures frame the individual schemes of each TSO for the externalities management and for the long-term locational signals. As a result, the respective organisational structures frame the coordination either by standardisation if all the individual schemes are identical or by combination when the individual schemes are different.

However, even if all the individual schemes are identical, some may ease the coordination because they provide more information. For instance, Cadwalader *et al.* [1999] envisioned coordination between nodal systems since quite a long time while coordination between redispatched systems is more demanding (Marinescu *et al.* [2005]). The coordination may then require an inter-TSO mechanism if the individual schemes completed by data exchanges are not enough. Such mechanisms already exists as for externalities management schemes as for the standardisation of network tariffs: the acceptance of grand-fathering rights, the implementation of explicit auctions, or of inter-TSO compensation schemes (ETSO [2005]). Nevertheless, nodal methods must be preferred for coordination since they are the only methods that efficiently internalise not only internal loop flows but also border effects.

Therefore, the coordination between TSOs in itself has also an organisational dimension since coordination must also be desired by the organisational structure of transmission. Otherwise, the TSOs may have difficulties in communicating necessary data and the modules may be unfitted as they may internalise only part of border effects. In the case of existence of such a competent supra-organisation (regulator or government) surrounding the parties to be coordinated, an evolution from a coordination by combination to a coordination by standardisation through the fitted modules is possible. Otherwise, such a concerted mobilisation is highly improbable and hard to gather (Glachant *et al.* [2005]).

IV. Empirical analysis and practical results of PJM and NGC

The common modular analysis framework and the study of compatibilities between its modules will be applied on the two TSOs PJM and NGC. They are two references of TSOs in the context of a wholesale power market but with quite opposite organisational structures. Our modular analysis will allow for a comparison of these TSOs to the ideal first-best one previously described. The study of each TSO will follow our modular analysis completed by an analysis of compatibility thanks to its organisational structure. Hence it would give us elements to understand the heterogeneity between the management schemes and their results.

IV.A. Modular analysis and compatibility requirements of PJM

PJM is often quoted as an example to be followed for the creation and implementation of system operator ruling wide areas. In particular, it uses nodal pricing and such a wide operator solves an important part of the seams issues. However, even if systematic solutions were implemented to solve the issue of network investments, they must still be improved to ensure a long-term efficiency regarding the adequacy of the network to the market and reliability needs. Inherited of the multi-level regulation and of the inertia of the industrial structure, the governance of such asset-poor SOs is appropriated to solve these coordination issues but raises problems for the network investments.

IV.A.1. The use of nodal pricing to extend

After facing some gaming issues in the late 1990's while trying to manage congestion thanks to zonal pricing, PJM engaged itself into implementing nodal pricing in its control area and expanding its control area to neighbouring utilities areas. PJM became an example of applied FERC's Standard Market Design for a part of the Northeast USA. For the moment, the nodal pricing system of PJM deals only with congestion while losses and voltage constraints are managed through less refined ways such as fixed rates.

The control of the amount of losses may also become of great concern when the efficient use of energy is appearing in the political debate. Even if the geographical expansion of PJM makes it more difficult to analyse the evolution of networks losses, an analysis is possible if we focus on period when the PJM control area is geographically stable.

Figure 3 Evolution trends of EHV network losses vis-à-vis energy generation on the PJM control area from June 2000 to December 2001 and from January 2002 to April 2004 (own calculus from PJM data)

Thus, the increasing trend of losses on the PJM control area is quite noticeable at least on the EHV network[5]. The management of losses thanks to fixed rates temporally differentiated doesn't provide sufficient locational information about the impact of the network users' behaviour and sufficient incentive to reduce amount of losses. Moreover, PJM as a system operator is not incentivised to control the amount of losses.

IV.A.2. The network development evolving but still to be improved

As far as the development of network is concerned, the FERC manifested great care about the absence of economical arbitrage in the decision process for network investments (FERC [1999], PJM [2004a]). Indeed, the expansion of the PJM control area may explain the increase of the gross congestion rent (see Chart 5) but it is more difficult to explain its augmentation vis-à-vis its energy consumption only by its geographical growth (see the blue and wider bars and the right scale on Figure 4). Other control areas of the Northeast of the USA such as NYISO face the same problem of an increasing congestion rent that seems

[5] It comprises transmission facilities until 350kV.

related to a lack of network investments based on an economic arbitrage. Before mid 2004, the network investments in the PJM areas were only made on security criteria.

Year	Congestion charges ($ million)
1999	53
2000	132
2001	271
2002	430
2003	499
2004	808

Chart 5 Evolution of the congestion rent ($ million) on the PJM control area from 1999 to 2004 (Source PJM [2005])

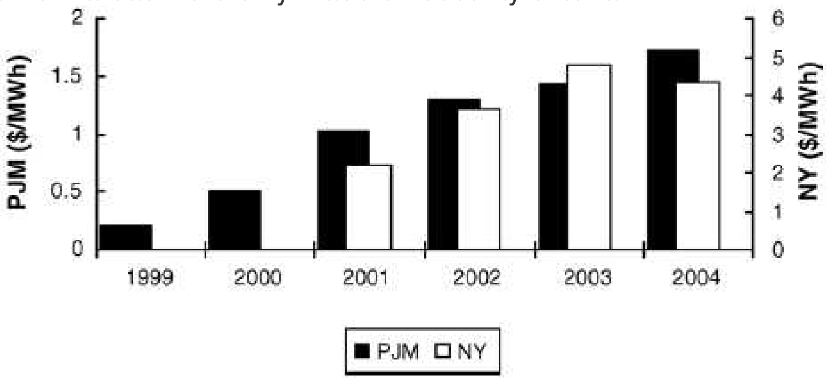


Figure 4 Evolution of the congestion rent on the PJM control area vis-à-vis the energy consumption from 1999 to 2004 (Rossignoli *et al.* [2005])

Since then, PJM has defined the concept of Economic Planned Transmission Facilities to develop the network of its control area on criteria based not only on reliability but also on economic efficiency (PJM [2004a]). Before the definition of this concept, the economic arbitrage of the network was supposed to be done by market agents thanks to merchant transmission investments thanks to FTR created by the network project (PJM [2004a]). This idea is similar to the Hogan's one [1992 and 2003] of a decentralised transmission market. Very few merchant transmission investments exist within the PJM area and within other RTO areas because they are very risky investments.

The need for such network investments is quite obvious regarding the 34 projects hence triggered after April 2004. A majority of these investments will be efficient within less than one year and some within few months (Joskow [2005a]).

Nonetheless, this economic criterion seems quite odd. The arbitrage between short-run operation costs and investment costs is made without directly calculating congestion cost but estimating it thanks to FTR (Joskow [2005a], PJM [2004a]). Moreover, neither losses nor unsupplied energy are taken into account during the decision process. Investment decisions are eventually made thanks to a snapshot, ignoring dynamic effects and uncertainty about future flows (Hogan [2005b]).

In this context, the long-term signals to guide the location of the network users are needed to limit the wideness of congestion on the network. On the PJM system, they are both deep cost ones for new investments and zonal use of the system tariffs for pre-existing assets. The use of the system tariff is partly based on no coordinated bundled tariffs fixed by the state regulators and on utilities' requirement for the use of their networks by the wholesale market (Joskow [2005b]). Their possible incoherence is not of great concern since the Use of the System tariff is only from 4 (ComEd zone) to 7.1%[6] (Rockland zone) of the energy price for the year 2004 and only paid by consumers. The deep cost allocation method used lacks accommodation capacities to be auditable to transmission-poor investors such as IPP. Hence, the nodal prices while unsuited to this long-term goal are the sole relevant locational signals.

IV.A.3. Coordination as the main work of RTO/ISOs

The PJM control area is crossed by a lot of loop flows from the Midwest export area to the east import areas such as NYISO and TVA (DoE [2002]). The loop flows may

[6] Here, the CESI [2003] example of a representative consumer with an installed capacity of 2.5MW consuming 10GWh a year is used. The mean price in the ComEd zone in 2004 was 30.61$/MWh and the mean price of the Rockland zone was 45.20$/MWh.

be difficult to manage and PJM faces seams issues. It raises some problems of security and some economic inefficiencies because of a lack of internalisation of externalities and border effects. The integration of the large utility area of Allegheny Power (PJM [2004b]) shows that the management of these effects may greatly modify the pattern of flows and that PJM is used to managing such situation. More broadly, PJM has recently signed joint agreements, a reliability coordination one with both Midwest ISO and TVA (MISO-PJM-TVA [2005]) and an operating one with Midwest ISO (MISO-PJM [2005]) in order to couple their nodal pricing systems and their regional transmission expansion plans. Other projects of coordination (a real-time one between ISO-NE and NYISO [2003] for instance) and the recent creation of the Midwest ISO tend to show that the ISO/RTOs are coordinators upon utilities' network to provide an open and non-discriminatory access to network and a wider wholesale market area. They can easily coordinate to ease arbitrage between control areas.

IV.A.4. A structure of governance also imposed by a multi-level regulation

As mentioned above, the creation of not-for-profit self-regulated ISO is a compromise between the wideness of border effects, the possibility to modify the industrial structure of the power supply chain and the difficulty to regulate an asset-poor SO. The clarity of the regulation may also be determinant in the choice of a self-regulated organisation.

The USA faces a dual regulatory structure as a mirror of its federal structure with one federal energy regulator, the FERC and fifty state regulators, the Public Utilities Commissions. The deregulation process is mainly lead by the FERC whose the jurisdiction is limited to the wholesale market. The desirability of deregulation differs from state to state whose the jurisdiction contains not only retail market but also bundled activities among other things transmission. This makes the dynamic of the deregulation process quite inhomogeneous and so incompatible with the numerous seams issues (Joskow [2005b]). Therefore, a long-term unified wholesale market cannot be ensured without the thorough participation of the transmission network.

Moreover, the fair representation of the network users is questioned in the ISO/RTOs. An overrepresentation of the generators is common among ISO/RTOs (Boyce-Hallis [2005]). They may then act under an unclear political pressure from different lobbying groups. In particular, generators prefer congested networks to use local market power. The costs control of the network management may not be clearly ensured thanks to a self-regulation with such an overrepresentation but hard to impose otherwise.

The FERC [1999] tried to overpass these obstacles thanks to Order 2000. It requires the transmission owning utilities to join and transfer the operation of the network to Regional Transmission Organisations. Such entities are responsible of system operation, among other things of the coordination of a regional planning process. As a consequence, PJM has implemented the concept of Economic Planned Transmission Facilities. Even if this concept has some flaws, it is a first step for an asset-poor SO to manage the network development in the long term.

The governance and regulation of PJM hence framed dictate the solutions chosen for its constituting modules. Since an asset-poor self-regulated SO supports with difficulties a cost control of a redispatch scheme, the nodal pricing is the short-run network externalities management scheme the more appropriated. Its not-for-profit structure makes it indifferent to the counter-incentive effect of the congestion rent.

Nevertheless, nodal pricing implies huge distributional changes (Kirsch [2000]), and FTRs were first allocated to limit these effects (Shanker [2003]). This issue of political economy is evolving with the redesign of the FTRs market but there are still regulatory concerns about the priority given to historical transactions (PJM [2005]).
Meanwhile, a nodal pricing completed with a FTRs market allows for an efficient dispatch and eases part of the coordination with neighbouring areas since it relies on a model very near the network configuration. The deep cost allocation method guides the location of network users but still needs the publication of accommodation capacities to limit its entry barrier effect. The new concept of Economic Planned Transmission Facilities may be part of the solution for efficient network investments but remains limited since the investment criterion misses some system operation costs and risk assessment. Such a systematic criterion may be a second best solution in the context of an asset-poor self-regulated SO difficult to incentivise.

IV.B. Modular analysis and compatibility requirements of NGC

Despite its flawed externalities management scheme, the operation cost of NGC is under control and the network investments are satisfactory, that is to say consistent with the regulation and the need of the wholesale market. Besides, the ability of the zonal use of the system tariff to impact the location of the network users is still to be proved and the coordination with its neighbouring TSOs seems to be a secondary problem because of its network topology that is little meshed. The performance of costs control is related to the organisational structure of NGC easy to incite while the other characteristics of its network management are mainly related to political economy.

IV.B.1. Flawed externalities management schemes and pragmatic solutions

Since the beginning of the liberalisation process in England and Wales, the congestion has always been managed thanks to redispatch. Even the introduction of the NETA didn't change that despite its well-known flaws noticed in the UK Pool. Nonetheless, the introduction of an incentive rate system in 1994 and the possibility to arbitrate between different marketplaces (NGC [2004a]) has allowed to reduce significantly the congestion cost (see Figure 5).

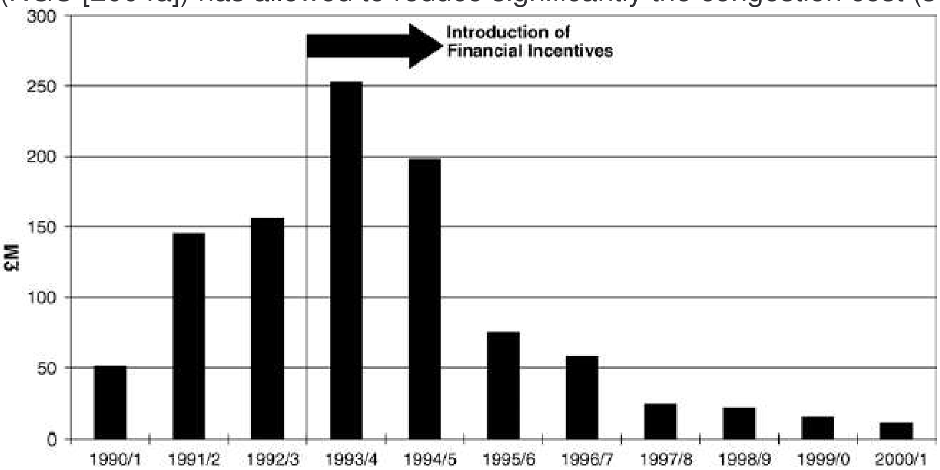
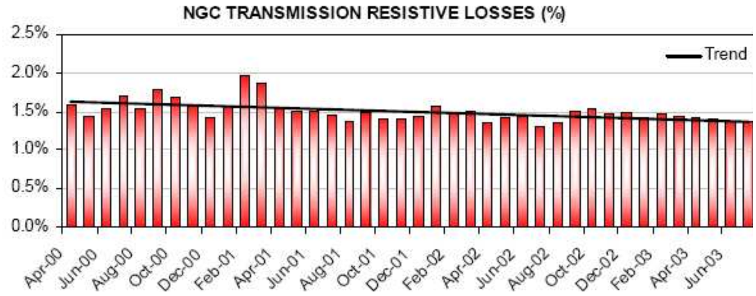


Figure 5 Evolution of congestion cost on the NGC network (Rossignoli *et al.* [2005])

NGC manages congestions on a medium-run basis over various months. The regulatory scheme consists as much in incentivising the TSO to improve the schedule of its operation as to reduce the market power in itself. Indeed, NGC anticipates the flow patterns thanks to the availability of generators. NGC can modify its schedule of maintenance operation to arbitrate between the cost of maintenance and the cost of congestion (Brunekreeft *et al.*

[2005]). NGC can also contract an option with potential reliability-must-run generators (NGT [2005a]) to reduce its exposition to a local market power.

A similar observation can be made on the management of losses. Under the NETA, the losses are a shared financial responsibility of generators and consumers on the basis of 45/55 ratios thanks to Estimated Transmission Losses Adjustments rates communicated by Elexon[7]. At the same time, NGC is incited to manage the amount of losses optimising the topology and the voltage plan. As a result, although the network users do not know their locational influence on losses and thus are not incentivised to reduce power losses, we notice a decreasing or at least stable trend of losses.



Source: NGC

Figure 6 Losses on the NGC's network and trend (Joskow [2005a])

IV.B.2. Satisfactory network investments despite unclear economic criteria

The network development is ruled by two complementary regulatory budget constraints. The short-run one called System Operator regulatory scheme is related to the system operation thanks to a performance-based regulation. As mentioned above, it prompts NGC not only to manage congestions and losses jointly with the schedule of maintenance operation but also to arbitrate between the short-run and medium-run operation costs and some small-scale network investments since these investments have short paybacks. The long-term regulatory budget constraint imposed on the network investments called the Transmission Owner regulatory scheme is a RPI-X regulation. As we will show it after, these budget constraints coupled with the governance of the TSO are normally enough to ensure a network capacity quite near the optimal one.

This set of policies seems to prove to be efficient whereas the OFGEM [2004a] guidelines concerning the economic justification of network developments are quite fuzzy and NGC [2004b] (see also OFGEM [2004a]) justifies the network development more by engineering criteria. The operation costs decrease (Figure 5 and Figure 6) and the investments are made while respecting the regulatory contracts (OFGEM [2004b]). It seems the level of the RPI-X regulation was quite well defined since efficiency gains permitted to reduce controllable costs by more than half in a decade (see Figure 7) while there was a 40% reduction of transmission cost (NGT [2005b]).

[7] See its web site www.elexon.co.uk. It is a subsidiary of NGC that is responsible of managing the balancing mechanism.

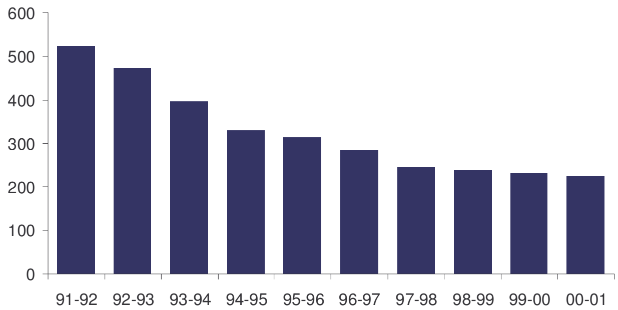


Figure 7 Controllable operating costs (£m) on the NGC's network (NGT [2005b])

Nonetheless, the incitement to an efficient location of the network users may need to be improved. A zonal tariff introduced in 1994 at the time of the dash for gas completes this scheme in order to compel the generators to arbitrate between the cost of transporting their primary energy and the cost of connecting to the power transmission network, Some importing zones have negative tariffs to attract new connections of generators.

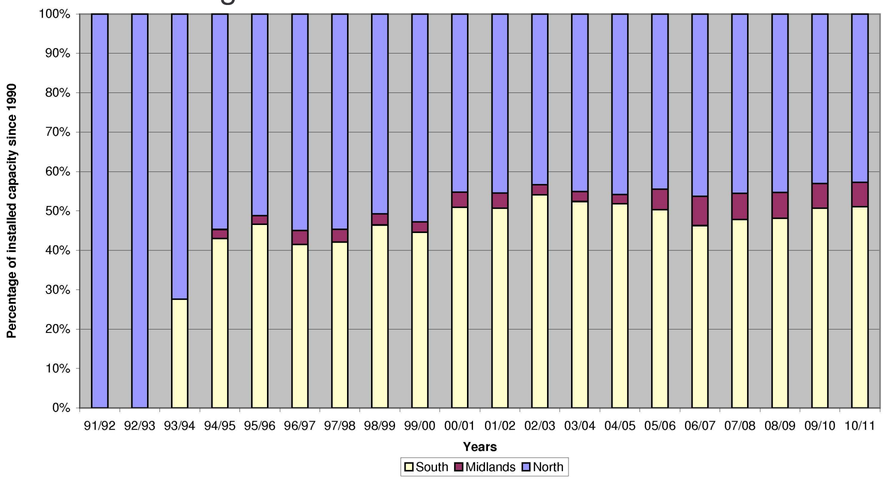


Figure 8 Cumulative dispositions of new capacities since 1990 (own calculus – data from NGC [2004b])

The results of the use of this methodology are quite mixed as shown on the Figure 8. A majority of the connections is in the South part of the NGC network but there are still a lot of connections in the North part of the NGC network despite the tariff differential. With a mean energy price of 25£/MWh, the maximum tariff differential stands for 11%[8] of the energy price. With the same hypothetical consumer as before, the maximum tariff differential reaches 13%. Given the availability of accommodation capacities and the degree of competition in the NGC control area, the use of a deep cost allocation method would be relevant regardless of the treatment of network demanding generators such as wind farms.

IV.B.3. Few loop flows from the neighbouring control areas on the NGC network

The geographical position of the NGC control area requires only a minimum need of coordination with neighbouring areas. The flow through the DC interconnector between France and England could be independently adjusted. And even the Scottish interconnector is quite easy to tackle because of its quite radial nature. Therefore, NGC faces almost no border effects from its neighbouring TSOs. Then the

[8] Here, we consider the CESI [2003] example of a representative producer with an installed capacity of 400MW consuming 2.5TWh a year.

coordination schemes are quite basic. The interconnector between France and England is only managed thanks to explicit auctions. The Scottish interconnector was managed thanks to a predefined share of the interconnector between the users mainly Scottish Power and Scottish and Southern Energy. The NGC's ability of coordination as the British System Operator might be challenged as the BETTA goes alive and extends the NGC control area to the Transmission Owners Scottish Hydro-Electric Transmission Limited and SP Transmission Limited.

IV.B.4. The organisational structure as determinants of an efficient network development

The British deregulation process gave birth to a fully unbundled and private TSO that own the network and to a unique heavy-handed regulator. Therefore, the core of the regulation of a profit maximising TSO is the pressure of financial incentives. It is also influenced by secondary regulatory requirements.

The ownership of the network by the System Operator allows for an efficient development of the network for two reasons. First, the revenue from the network ownership ensures that financial penalties on either the SO or TO regulatory scheme would not jeopardise the survival of the TSO. Second, the association of the SO and TO regulatory schemes imposed to NGC guarantees the arbitrage between short-run and medium-run operation costs and larger-scale network investments (Joskow [2005a]). The SO regulatory scheme entices NGC to arbitrate between short-run operation costs and small-scale investments. The TO regulatory scheme entices NGC to arbitrate between small-scale and large-scale investments all the more that there are economies of scale in investing the transmission network and that the budget constraints can be renegotiated with the OFGEM.

Under such a heavy-handed regulation, a nodal pricing could have been more advantageous (Green [2004]) in sending appropriated economic signals to the market actors. However, at the time of (re)designing the English and Welsh power market, the consumers feared that their bill increased and the generators that their revenues decreased while the network would have the rent (Green [1997], OXERA [2003]). Similarly, the OFGEM tried to enhance the locational signals on the NGC network by imposing differentiated loss factors but failed. It was a loser-loser measure since producers are mainly in the North and consumers are mainly in the South (OXERA [2003]).

Despite a competitive market that would require a deep cost allocation method for the network charges, a zonal tariff is used to reduce the entry barrier on network demanding generators. First, such a tariff prevents the allocation method from being far too discriminatory (Green [1997]). It is part of a policy to promote the Renewable Energy (OFGEM [2003]) and it may have been justified at the beginning of the deregulation to limit the entry barriers to new entrants.

The coordination of NGC with its neighbouring TSOs is limited not only because of the topology of the NGC network but also because of the organisational barriers. The pay-as-bid structure of the auctions of the France-England interconnector may be hard to change to reach ideally a coupling between France and Great Britain. Indeed, this interconnector is a separate merchant business out of the scope of the OFGEM (Joskow [2005a]) and changing the related allocation method may reduce the profit that NGC earns from it. The flow on the Scottish interconnector was quite predictable, on top from Scotland to England because of the overcapacity of the Scottish energy producers. The industrial structure of the Scottish power industry also impacts it since there are only two power companies Scottish and Southern

Energy and Scottish Power. Then, the access to the Scottish interconnector would not be very competitive under an auction, which justifies the use of administrative rules. This consistent with the Scottish interconnector now being part of the British system operation and then being managed thanks to redispatch.
To conclude, there is not really a better way to be away from the first best TSO since each context is peculiar and the job to be done is mainly determined by the configuration of the network, its incumbent capacity and regulation. The NGC control area is peculiar case because the insularity of Great Britain. Hence, NGC does not face the common European conflicts of interests between coordination of neighbouring control areas and financial stakes of developing the national networks. Therefore, coordination is only a secondary issue to NGC while the network development is its core activity. In the USA, the System Operators (in particular PJM) are regional coordinators and the network development was only a secondary issue let to the market actors without any success. As the coordination is a solved issue in the PJM area, the network development is becoming of importance to avoid a market balkanisation.

V. Conclusion

Our modular analysis framework that gathers the operational missions of TSO as for the management of the flows on its network and completed by the organisational structure of transmission demonstrates that the institutional context and the regulatory policies imply compatibility requirements on the implementations of the network management schemes.
Our empirical analysis concludes in a quite opposite than other drastic views (Boucher-Smeers [2001], Ehrenmann-Smeers [2005], Hogan [2003]). Some network management schemes may be inefficient compared to an ideal first-best TSO but relatively efficient regarding the institutional context surrounding their implementation all the more regulation may limit inefficiency in some cases. There are two reasons to this statement. First, the institutional context can limit the set of feasible network management schemes in such way that only inefficient solutions can be implemented. Indeed, institutional constraints must not be considered as secondary ones but as the ground of the implemented network management schemes. Secondly, regulation can complete these inefficient management schemes in an efficient way to reach unexpected satisfactory results by providing the good incentives to the appropriated actors and/or by imposing the relevant criteria. Therefore, even inefficient implementations of network management schemes must be deemed and studied because they may be the only ones to be possible given the context. Hence inefficiency could be measured rather than noticed from more or less painful experiences. Complementary rules could then be designed to limit its undesired effects.
However, the efficient solutions are still the target to be reached (Boucher-Smeers [2001], Ehrenmann-Smeers [2005]) thanks to the relevant institutional ground or its modification since they may ease the creation of wide market areas. Meanwhile, in the context of a meshed power transmission network and of a subsidiarity, the windows of feasibility of such simultaneous modifications are short and limited (Glachant *et al.* [2005]). As a consequence, this anticipation of continuation of inefficient solutions makes the study of non-optimal management schemes such as Pérez-Arriaga - Olmos [2005], Marinescu et al. [2005], or ETSO-Europex [2004] more necessary.

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