Degree of coordination in market-coupling and counter-trading

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Abstract

Cross-border trade remains a contentious issue in the restructuring of the European electricity market. Difficulties stem from the lack of a common market design, the separation between energy and transmission markets and the insufficient coordination between Transmission System Operators (TSOs). This paper analyzes the cross-border trade problem through a set of models that represent different degrees of coordination both between the energy and transmission markets and among national TSOs.

We first present the optimal organisation, not implemented in Europe, where energy and transmission are integrated according to the nodal price paradigm and Power Exchanges (PXs) and TSOs are integrated. This is our reference case. We then move to a more realistic representation of the European electricity market based on the so-called market-coupling design where energy and transmission are operated separately by PXs and TSOs. When considering different degrees of coordination of the national TSOs' activities, we unexpectedly find that some arrangements are more efficient than the lack of coordination might suggest. Specifically we find that even without a formal coordination of the TSOs' counter-trading operations, non discriminatory access to

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common counter-trading resources for all TSOs may lead to a partial implicit coordination of these TSOs. In other words, an internal market of counter-trading resources partially substitutes the lack of integration of the TSOs. While a full access to counter-trading resources is a weaker requirement than the horizontal integration of the TSO, it is still quite demanding. We show that quantitative limitations to the access of these resources decrease the efficiency of counter-trading. The paper supposes price taking agents and hence leaves aside the incentive to game the system induced by zonal systems.

1 Introduction

Experience indicates that the restructuring of the electricity sector towards competition is more complicated than foreseen. Specifically while the application of first economic principles on Kirchhoff's laws tells us that electricity should be differentiated by location and hence that the energy and transmission markets should be integrated, the argument that this makes the market unnecessarily complicated has been widely advocated. The pressure for market organizations based on a coarse geographic differentiation of the product has thus been considerable. Similarly the lack of storability of electricity suggests the need for a very strong coordination among all agents involved in the market. Here again the argument has been that this departs too much from normal market operations, leading to a considerable pressure to retain as much decentralization in the market as possible. This joint pressure for a loose geographic differentiation of electricity prices and a rather decentralized organisation of the energy and transmission markets has been encountered throughout the world. It is also present in Europe where the problem is made more acute by the legal requirement to construct a single electricity market.

These difficulties have been particularly striking in the organisation of cross-border trade among Member States that stakeholders have now been discussing since more than 10 years. This paper attempts to model different market organisations inspired by these discussions and the possibilities offered by the third legislative package (see [6]) to introduce multinational Transmission System Operators (TSO) to deal with congestion issues.

It has now been abundantly argued both on the basis of theory and successful restructuring experiences that electricity markets should rely on an organization where transmission and energy clear simultaneously at spatial level. This system is now implemented in the restructured part of the US electricity market. The model accounts for the physical properties of the electricity commodity and the characteristics of the grid. We refer to this situation as *Model 1* and take it as our benchmark. From an economic point of view, Model 1 represents a complete market where all spatial arbitrage opportunities allowed by the physical constraints of the grid are traded away.

While this type of market exists and is operated successfully in different regions of the world, it is not accepted in Europe. The most sophisticated organisation of cross border trade in the continental European electricity market is known as Market-Coupling (MC) (see Belpex web site). It is currently operated between Belgium, France and The Netherlands and should soon be extended to the Western border of Germany. This organisation can be described as follows. TSOs provide the national PXs with a simplified representation of the network that is meant to represent its transmission possibilities. The PXs then clear national and international energy markets within the simplified representation of the grid. Because the resulting power trades are not necessarily feasible for the real network, TSOs undertake "counter-trading operations" in order to re-balance the flows and make them compatible with physical grid constraints. We refer to this problem as *Model 2* when all TSOs act in a fully integrated way to manage network congestion. By using a simplified description of the grid, Model 2 misrepresents spatial arbitrage possibilities and organizes an incomplete market.

The current organisation of market-coupling is different and may still evolve. The situation today is that each TSO manages congestion on its national grid with multilateral arrangements controlling congestion on the interconnections. Because of loop flows, the actions of each TSO or group of TSOs have an impact on the network of the other TSOs. We refer to this situation as *Model 3* of which we consider different views. These view are inspired by the third legislative package that allows for multinational TSOs, that is TSOs that cover several countries. Model 3 further degrades the situation compared to Model 2 by organizing an incomplete transmission market.

All real world markets have some degree of inefficiencies and it is not certain ex ante that those embedded in Models 2 and 3 are serious, at least if one neglects the incentive to game counter-trading operations as we do here. It all depends on the particular situation on hand, that is, on the capacities of the grid and the structure of generation and demand. These things can only be appreciated by numerical testing. We introduce these models on a stylized example (see [1] for the mathematical details) and apply them on a small prototype model of the pentalateral market where market-coupling is currently developed (Belgium, France, Germany, Luxembourg and The Netherlands). Surprisingly we find that the lack of formal coordination of the counter-trading operations embedded in Model 3 can be partially substituted by a competitive access to counter-trading resources. In other words an internal market of counter-trading resources can in principle restore some of the efficiency that the lack of integration of the TSOs normally entails. While this is a weaker requirement than a full integration of the TSOs, it is still demanding. We show that quantitative limitations to the access of these resources effectively decreases the efficiency of counter-trading.

The problem treated here arises from the need to spatially differentiate electricity in a grid constrained market. The so-called RTO or ISO organisation that now prevails in several regions of the US recognizes the need for a tight integration of the energy and transmission operations. This model (that we stylize in Model 1) is now well understood; it is briefly recalled in Section 2 together with Chao and Peck (1998, see [2]) six node example that serves to support the conceptual discussion in Sections 3 and 4. Europe is pursuing a different approach[1]. "Market-coupling" (MC) is today the most advanced European arrangement of cross-border trade. It supposes that national PXs clear the multi-area energy market on the basis of a simplified ATC (available transmission capacity) description of the grid and leaves it to the TSOs to tackle the resulting congestions. We describe the energy market clearing part of MC in Section 3. While an integrated European TSO would be in the best position to tackle the congestions resulting from the clearing of the energy market Europeans are still hesitant as to the degree of integration of transmission that they want to implement. Section 4 examines different possibilities for organizing counter-trading operations and discusses the unintended but positive impact that some of these methods can have. Section 5 introduces a stylized case study that is then elaborated in Section 6. Conclusion terminates the paper.

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[1] For more information, see the electricity section in the "Florence Forum" on DG Energy at: http://ec.europa.eu/energy/gas_electricity/forum_electricity_florence_en.htm

2 The six node example and Model 1: the integrated energy and transmission markets

We introduce the different models on Chao and Peck's six node example (see [2]) depicted in Figure 1. The network is composed of eight lines of which (1-6) and (2-5) have limited transfer capacity. Generators operate in nodes 1, 2 and 4 and consumers are located in nodes 3, 5 and 6. The network is represented by the standard Power Transfer Distribution (PTDF) matrix. The authors assume a "flowgate model" as is currently foreseen (but not implemented) in Europe. We therefore conduct the discussion in those terms even when assuming fully integrated electricity and transmission markets. The flowgate model can be interpreted as zonal or nodal depending on whether the flowgates link nodes or zones. The European view is that it should be zonal; we suppose price taking agents and hence assume away any incentive to game the system induced by the zonal system. Perfect integration supposes that PXs and TSOs are merged into a single entity (the ISO) that behaves as if solving a welfare optimization problem constructed on the basis of supply and demand bids. This model is well known and not elaborated on here. It is our Model 1.

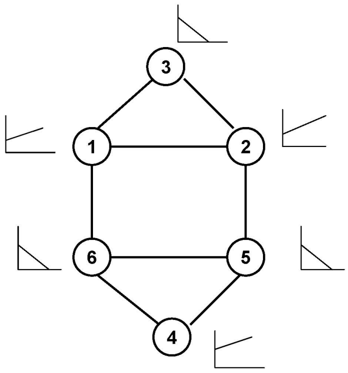

Figure 1: Six node market

3 Market-coupling (MC) and the clearing of he energy market

The restructuring of electricity in Europe has seen considerable resistance against the full differentiation of electricity by location. The MC organisation adopted in Central Western Europe is an intermediate arrangement. In this approach, the energy market spatially clears on a zonal basis constructed on a simplified representation of the grid. It is the role of the TSOs to (i) provide the energy market with this simplified representation of the grid and to (ii) remedy any line overflow that appears after clearing the energy market. Models 2 and 3 are based on the same MC representation of the energy market, but differ by how TSOs tackle congestion.

An example of a two zones market is depicted in Figure 2 for the six node example. There exists two PXs, one for each zone; the imports/exports from one zone to the other are capped by some transfer limit which here represents the grid. This limit is an Available Transmission Capacity (ATC). The computation of the ATC and more generally the construction of the simplified representation of the grid by the TSOs go beyond the scope of this paper. The zonal PX clears the domestic market for given imports and exports. The different zonal PXs also simultaneously clear the cross-border energy market by playing on imports and exports in a way that accounts for the ATC between the zones. All in all, we can assume that the two zonal PXs operate in a coordinate way, as if they were just one PX, and their actions can be modelled as resulting from a welfare maximization conducted on all geographic zones and subject to the sole ATC constraints.

4 Counter-trading services

The clearing of the energy market operated by the PXs is a welfare maximization problem that finds a market equilibrium between the quantities of electricity offered and demanded in the whole six node market, taking into account the ATC representation of the network. This determines the electricity prices in the Northern and Southern zones. The price is unique in the two zones if the ATC is not congested. There are different prices otherwise. Because the energy market clears on an ATC model that may only be a very imperfect representation of the real grid, the resulting flows may

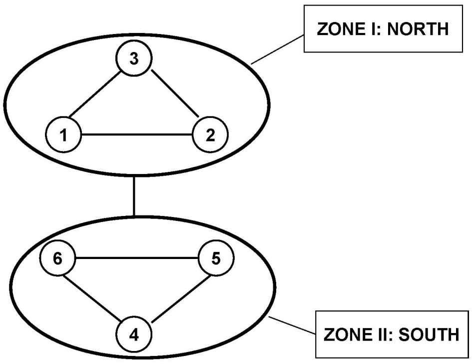

Figure 2: Zonal representation of the six node market

exceed the capacities of the physical lines. Counter-trading is an operation whereby TSOs trade incremental of decremental injections at the different nodes in order to remove the overflows that result from clearing the energy market on the sole ATC model.

Counter-trading can be organized in different ways: one possibility is for TSOs to jointly remove overflows at minimal cost. Another possibility is to have TSO "cooperate" in a more or less formalized way. Counter-trading has a cost which must be charged to the agents of the energy market. We compute this cost but do no examine here its impact on energy trade. We use the six node example to illustrate different degrees of coordination. In contrast with full coordination which is an unambiguous notion, there are many ways to think of imperfect coordination. The discussion that follows is thus by nature illustrative. Our final goal however is to characterize the lack of coordination in a quantitative way.

Let q_i be the vector of injections and withdrawals of the market equilibrium of the PX's welfare maximization problem obtained on the ATC network depicted in Figure 2. Assume, for the sake of the discussion, that the flows resulting from these q_i violate the capacity of lines (1-6) and (2-5) of the real network in Figure 1. TSOs can act on line flows by purchasing incremental or decremental generation or consumption of electricity Δq_i. This means that quantities produced (or consumed) can be shifted from one producer (or consumer) to another. These adaptations must be limited though. First, they should be feasible (not exceed plant capacity or lead to negative consumption or generation). Second, changes of generation should net out to zero for each TSO; similarly changes of consumption should net out to zero for each TSO. We introduce more or less coordinated ways of conducting this task.

Let TSO^N and TSO^S be the two TSOs in charge of the Northern and the Southern zones respectively. A first assumption discussed in Section 4.1 is to suppose that TSO^N and TSO^S jointly solve a unique optimization problem to minimize the total cost of removing the overflows resulting from the q_i. The alternative is to suppose that TSO^N and TSO^S separately act to remove line overflows taking into account the actions of the other. This leads to a Nash equilibrium problem. Sections 4.2.1, 4.2.2 and 4.2.3 present alternative formulations of this scenario. The mathematical problems and their economic interpretations are discussed in detail in a companion paper (see [1]).

4.1 Model 2: Integrated counter-trading

Integrated counter-trading is achieved when the TSOs of both zones operate jointly to remove line overflows at minimal cost. Note that TSO^N and TSO^S take as given the quantities q_i that result from the clearing of the energy market by MC. The model is an optimization problem (see the companion paper [1]): each TSO is in charge of buying and selling counter-trading services in its own area[2] at minimal cost, but the optimization is joint. It gives a single price for each counter-trading resource as well as for each congested line.

4.2 Model 3: Coordinated and uncoordinated counter-trading

As indicated above one can conceive of different imperfectly coordinated counter-trading in different ways. We discuss the economic effects of different approaches in this section.

4.2.1 Implicitly coordinated counter-trading: version 1 of Model 3

We first assume that each TSO acts *independently* to manage congestion on the interconnections, taking the actions of the other TSO as given. We further assume that each TSO can buy counter-trading services in both zones. This means that, differently

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[2] Respectively $\Delta q^N_{i=1,2,3}$ for the Northern TSO^N and $\Delta q^S_{i=4,5,6}$ for the Southern TSO^S.

from the case described in Section 4.1, both TSOs can trade at each node. We note the actions undertaken by the TSOs as $\Delta q^N_{i=1,\ldots,6}$ and $\Delta q^S_{i=1,\ldots,6}$. The network remains the common good shared by the TSOs but the absence of coordination may induce them to assign different values to the congested lines. The plurality of values is the source of a market incompleteness that can degrade the transmission market. In economic terms, this problem is a Generalized Nash Equilibrium (GNE). This problem generally has several solutions leading to different values implicitly assigned to the interconnections (see [1]).

The surprising effect of the situation is that, even in absence of full coordination, we find that the two TSOs have no choice but assigning the same value to the common transmission constraints. This has an economic interpretation. The model assumes that both TSOs trade the same counter-trading resources without limitation. They thus pay the same price for those resources. The price of counter-trading resources determines the value attributed to the congested lines. Identical counter-trading resource prices therefore imply identical valuations of the congested lines. Everything happens as if counter-trading were operated in an integrated way. The mathematical implication is that the solution of the GNE is the solution of the associated Nash Equilibrium, which differs from the GNE by assuming a market for the congested flowgates. The policy implication is that it does not hurt to keep separate TSOs if there is free access to global counter-trading resources. As we shall see this free access is required for the results to hold.

4.2.2 Uncoordinated counter-trading: version 2 of Model 3

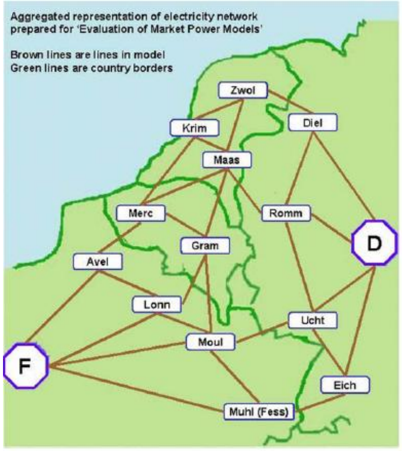
The above model assumes that both TSOs can resort to all counter-trading resources on an equal basis. TSO^N has no priority on Northern resources compared to TSO^S. This sets a single price of counter-trading for the two TSOs and hence indirectly insures the coordination of their activities. It is unlikely in practice that all TSOs would have equal access to all counter-trading resources. We therefore consider an alternative case where we suppose that TSO^N has limited access to the Southern resources and conversely. More specifically, we assume that TSOs only have limited access to counter-trading resources in other control areas and specify a bound on this access. A TSO that hits its quota in another jurisdiction therefore faces a scarcity rent that cannot be arbitraged away with the other TSO. Because counter-trading resources are now priced differently, the value assigned by the TSOs to the congested lines also differ and the perfect coordination is lost. This makes counter-trading inefficient.

4.2.3 Uncoordinated counter-trading: version 3 of Model 3

The limit case is the one where a TSO can only access the counter-trading resources of its own area and acts taking the actions of the other as given. This creates line valuation differences that cannot be arbitraged away. This destroys all possibilities of coordination and increases inefficiencies in counter-trading.

5 A case Sstudy

We now consider a pilot case study constructed on the basis of the network of the Central Western European (CWE) power market depicted in Figure 3. This network is composed of fifteen nodes connected by 28 lines with limited capacity distributed over four countries: Germany, France, Belgium and The Netherlands. Generators, consumers and different TSOs operate in the two Belgian (Merchtem and Gramme) and the three Dutch (Krimpen, Maastricht and Zwolle) nodes as well as in the two big French and German nodes. The other French and German nodes are inter-connectors used to transfer power only. As with the representation adopted in the six node example, the grid is modeled by using a PTDF matrix provided by ECN ([3]).



Flowgate	Reactance	Max Capacity [MW]
AVEL_LONN	22,2	2762
D_DIEL	45,9	20000
D_EICH	45,9	20000
D_ROMM	45,9	20000
D_UCHT	45,9	20000
DIEL_ROMM	69,2	1842
DIEL_ZWOL	12,2	2971
EICH_UCHT	41,3	3329
F_AVEL	45,9	20000
F_LONN	45,9	20000
F_MOUL	45,9	20000
F_MUHL	45,9	20000
GRAM_LONN	45,2	1207
GRAM_MOUL	156,5	267
KRIM_MERC	34,2	936
LONN_MOUL	27,1	1842
MAAS_GRAM	41,8	641
MAAS_KRIM	29,1	1842
MAAS_MERC	61,0	641
MERC_AVEL	55,4	898
MERC_GRAM	31,1	1842
MOUL_MUHL	38,2	3329
MUHL_EICH	11,5	1282
ROMM_MAAS	28,3	896
ROMM_UCHT	43,0	1842
UCHT_MOUL	25,4	1326
ZWOL_KRIM	33,1	1842
ZWOL_MAAS	50,0	1842

Figure 3: CWE power market

Adopting a standard technological representation of the power sector, we assume that eight electricity companies[3] plus a fringe of small competitors operate in this market and produce electricity running a set of eight different technologies[4] following an endogenously determined merit order.

We consider a time horizon of one year measured in hours per year, subdivided in two periods with different durations (respectively 5,136 h and 3,624 h) and different base load demand. Our focus is however not on the distinction between peak and base demand but on the geographical differentiation of electricity demand and generation.

A wholesale reference price of 40 €/MWh is applied as well as an elasticity of -0.1 in the reference point. Our simulations are calibrated with data updated to 2005. Demand data are provided by Eurostat while generation capacities come from the public reports of the power companies included in the model.

A PX and a TSO operate in each of the four modeled countries. They are integrated into a single pool in the reference "nodal model". Following European practice, they remain separated entities in the other cases. In line with the design of "market-coupling" we assume that an equilibrium mechanism links all PXs so that they behave in an integrated way as if there were a unique PX operating on a simplified network. On the contrary, TSOs can organize their activities in different ways as we explain in the following.

6 Modelling and results

We construct several models that correspond to different multinational TSO arrangements made possible by the third legislative package. These introduce various degrees of geographic coordination of counter-trading, which may in turn have different impacts on electricity trading. The models and the results are presented along the same philosophy as in the six node example: we proceed from full to no coordination. Model 1 describes the full integration of energy and transmission; it represents the perfect coordination where energy is fully differentiated by location (within the limits of our data). This arrangement is a "first best". The other models are of the MC type with

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[3] E.ON Energie AG, Electrabel SA, Electricité de France, ENBW Energieversorgung Baden-Württemberg, Essent Energie Productie BV, Nuon, RWE Energie AG, Vattenfall Europe AG.

[4] Specifically, hydro, renewables, nuclear, lignite, coal, CCGT, natural gas and oil base plants.

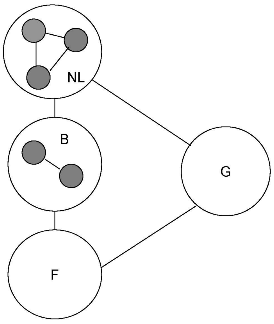

Figure 4: Stylized CWE market

a imperfect integration of energy and transmission in the sense that the energy market first clears on a simplified representation of the grid operated by the PXs and TSOs take care of possible line overflows in a second stage. Taking stock of the results of the MC problem, Model 2 supposes a fully coordinated counter-trading with a single TSO covering Belgium, France, Germany and The Netherlands. This implementation of market-coupling is a “second best”. It represents the most efficient implementation of the third package. Model 3 effectively consists of a set of models of alternative TSO arrangements.

All TSO operations are conducted on the flowgate description of the grid given in Figure 3. This representation is taken from [4]. In contrast the PXs operate on an ATC representation of the grid depicted in Figure 4. This representation supposes that the network is subdivided into four zones connected by ATCs. Market-coupling is currently conducted on an ATC model but a move to a “flow based” model (which is effectively a flowgate model) is foreseen for 2010. No information is available on the current organisation of counter-trading, the official philosophy being that a proper definition of the ATC suffices to solve grid problems. We now present these different models in more detail.

6.1 Model 1: The full integration of energy and transmission

All PXs and TSOs are integrated in a single entity. This is the standard "nodal system" (which is here effectively a zonal system because of data limitation). It avoids what Hogan calls "the fallacy of separation" and corresponds to Joskow's "textbook" model (see [5]). There is a single physical model of the grid, which is the one depicted in Figure 3.

The solution of this model highlights that congestion only occurs on the interconnections between Belgium and The Netherlands on one side and Belgium and France on the other side. The social welfare is 267,124,462,455 €. By construction, the flows resulting from the joint clearing of the energy and transmission markets are feasible for the grid.

6.1.1 Sensitivity analysis

We also conduct a simple sensitivity analysis on Model 1 by modifying the values of the reference demands used to calibrate the demand functions. We find that increases of the reference electricity demands by 5, 10 and 20% respectively lead to social welfares of 279,254,121,514 €, 291,080,340,843 € and 313,591,708,405 €.

6.2 The energy market in the "market-coupling" of Models 2 and 3

Models 2 and 3 separate the PXs and the TSOs. This falls into the "fallacy of separation" and departs from the successful "textbook" approach (see [5]). Following the principle of market-coupling we assume a different PX in each of the four markets but suppose that market clearing takes place on a geographic basis described by the ATC network of Figure 4.

The clearing of the sole energy market in Models 2 and 3 (that is the outcome of the coordinated activities of the PXs) leads to overflows on fourteen lines. These comprise both interconnections (Germany-Netherlands, Netherlands-Belgium, Belgium-France, France-Germany) and domestic (German, Dutch and Belgian) lines. The social welfare resulting from the sole clearing of the energy market, that is before removing violations of line constraints, amounts to 267,570,731,848 €. There is a welfare increase of 0,17%. This amounts to 446 million €/year. This increase is artificial though, as it is only permitted by violating line constraints.

6.3 Model 2: Market-coupling with integrated counter-trading

Because the clearing of the energy market in all cases but Model 1 relies on the simplified representation of the grid (Figure 4) its outcome is not necessarily feasible for the grid. A second step is thus required whereby TSOs engage in counter-trading in order to remove congestion, both national and on the inter-connectors. The third package allows for the inception of multinational TSOs, but does not impose them. Following the discussion of the six node example we introduce different organisations that also involve multinational TSOs. A first case supposes a single TSO covering the four countries and operating on the grid depicted in Figure 3. This constitutes Model 2.

The coordinated action of TSOs in Model 2 removes the line overflows occurring from the clearing of the energy market. The interesting result is that congested lines and marginal values of those lines are identical to those of Model 1. Counter-trading operations imply re-dispatching costs that decrease the social welfare by 4 Million €/year (-0.0015%) compared to Model 1. This is reported in Table 1. This loss of welfare is the price to pay for the separation of the energy and transmission markets. This price is here small: averaging the cost of counter-trading on the whole load of the region leads to a value of 0.374 €/MWh.

	Social Welfare (€)	**Re-dispatching costs (€/MWh)**
Model 1	267,124,462,455	
Model 2	267,120,396,787	0.374

Table 1: Welfare and average re-dispatching costs (Models 1 and 2)

6.3.1 Sensitivity analysis

Table 2 extends the sensitivity analysis to Model 2. As we did in Model 1, we consider increases of the reference electricity demand of 5, 10 and 20%.

Demand level for (B-NL) TSO	Total Re-dispatching costs	Average Re-dispatching costs	Welfare (PX)
Reference	450,335,061	0.374	267,120,396,787
Increase 5%	431,283,689	0.346	279,249,137,781
Increase 10%	549,816,403	0.426	291,066,310,376
Increase 20%	321,992,912	0.240	313,589,922,952

Table 2: Welfare, total and average re-dispatching costs (Model 2)

The average re-dispatching costs now amounts to 0.346, 0.426 and 0.240 €/MWh for 5, 10 and 20% increases of the energy demand respectively. Welfare losses with regard to the corresponding scenarios of the sensitivity analysis of Model 1 are respectively 4.9, 14 and 1.7 Million €/year. Neither average re-dispatching cost or welfare loss is monotone with load because congestion is not monotone with load.

6.4 Model 3: Market-coupling with imperfect coordination of TSOs

The history of European cross border trade reveals that stakeholders prefer bilateral arrangements to integrated solutions. The results of Model 2 showed that the only congestions remaining after integrated counter-trading operations are those of the interconnections between France and Belgium and Belgium and The Netherlands. This suggests a less integrated approach where congestion problems are handled in the regions where they occur. Model 3 considers a set of these approaches as we describe now.

6.4.1 Model 3.1 : A trilateral TSO (F-B-NL)

The sole congestion on interconnections between France and Belgium and Belgium and The Netherlands suggests an organisation whereby a single TSO covering the Belgian, French and Dutch markets manages congestion by counter-trading in these three countries (this is the current trilateral market (see Belpex web site)), leaving German injections and withdrawals identical to those determined in the clearing of the energy market. We depict this situation on Figure 5.

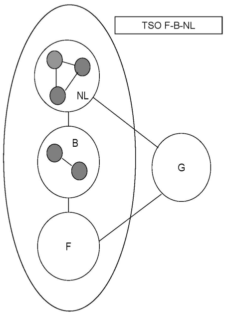

Figure 5: A trilateral TSO (F-B-NL)

Since there is a multinational TSO in charge of removing congestion occurring in the Belgian, French and Dutch market and there is no action by the German TSO, the problem boils down to a single optimization problem where the trilateral TSOs (F-B-NL) eliminates congestion at minimal welfare loss.

We find that the re-dispatching cost slightly increases compared to the one observed in Model 2. Welfare amounts to 267,116,142,245 € which corresponds to losses of 4.2 (0.002%) and 8.3 million €/year (0.003%) with respect to the values obtained in Models 2 and 1 respectively (compare to Table 1). Welfare losses increase compared to Model 2 because the German TSO no longer contributes to counter-trading. This may look surprising as there is no residual congestion on the lines with Germany in the outcome of Model 2 and a pure ATC reasoning would suggest that there is thus no reason to involve the German TSO. However Kirchhoff's laws justify involving this TSO in order to reduce the overall cost of congestion. This illustrates the fallacy of the idea of removing congestion at the local level. Averaging the re-dispatching cost over the load of the trilateral market gives 0.693 €/MWh. Averaging this re-dispatching cost over the whole load gives 0.377903 €/MWh (approximately 0.378 €/MWh). Needless to say the German TSO is likely to object to charging operators in its control area in order to contribute to congestion relief in the trilateral market.

6.4.2 Model 3.2 : A hybrid system: one trilateral TSO (F-B-NL) and two bilateral TSOs (G-NL) and (G-F)

It is known (and confirmed by sensitivity analysis) that congestion can occur on the Germany-Netherlands and France-Germany interconnections. Generalizing the decentralized view of counter-trading, one introduces an organisation whereby three multilateral TSOs intervene to manage congestion. Specifically, we keep the (F-B-NL) TSO for handling congestion in the trilateral market but also introduce two bilateral TSOs (G-NL) and (G-F) to manage congestion on the Dutch-German and French-German interconnections respectively. This new arrangement, aimed at increasing coordination among TSOs, is depicted on Figure 6.

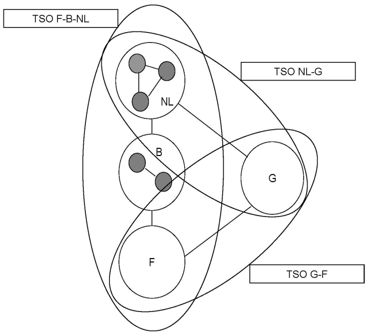

Figure 6: The trilateral TSO (F-B-NL) and two bilateral TSOs (G-NL) and (G-F)

Invoking the discussion of Section 4.2.1, one observes that this arrangement creates arbitrage possibilities on Dutch and French counter-trading resources respectively; these are traded away if (F-B-NL) and (G-NL) pay the same price for Dutch counter-trading resources and (F-B-NL) and (G-F) similarly pay the same price for French resources. We thus end up in a situation where even though (F-B-NL), (B-NL) and (G-NL) behave in principle in an uncoordinated way, their paying identical prices for counter-trading resources on some markets implicitly forces some coordination between them. Our simulations confirm this reasoning: we obtain the results of the explicit TSOs' coordination of Model 2.

We mentioned in Sections 4.2.1 and 4.2.2 that this problem is a Generalized Nash Equilibrium and hence generally has many solutions (depending on the bargaining power of the different agents). It is remarkable that our attempts to find alternative solutions by giving more or less weight to some TSOs failed: the sole fact of the different TSOs paying the same price for common counter-trading resources forces the implicit coordination that leads to the same outcome as the explicit coordination of Model 2.

This desired result does not come for free. It requires that TSOs have non-discriminatory access to common re-dispatching resources (Dutch resources for (F-B-

NL) and (G-NL) and French resources for (F-B-NL) and (F-G)). As explained above, even though there is no explicit trading of interconnection capacities at the counter-trading level in Model 3.2 (in contrast with Model 2), the fact that TSOs or groups of TSOs resort to identical counter-trading resources for which they pay the same price implies that they effectively see the same value for interconnections capacities. The set of solutions of the Generalized Nash equilibrium reduces to the single solution of the associated Nash Equilibrium problem where interconnections capacities are effectively traded among TSOs. This is the result achieved by perfect coordination of the counter-trading operations in Model 2. The next model delves somewhat deeper into what happens when one relaxes the assumption of non discriminatory access to counter-trading resources.

6.4.3 Model 3.3 : A mental experiment: two bilateral TSOs (F-B) and (B-NL) in the trilateral market

We delve into the implicit coordination mechanism underlying Model 3.2 by considering a simplified situation where the trilateral TSO (B-F-NL) is split into two bilateral TSOs (F-B) and (B-NL) that separately take care of the congestion in the sole trilateral market. The case focuses on the implicit coordination that automatically occurs as a result of non discriminatory and unlimited access to the resources common to these two bilateral TSOs (here Belgian resources). This arrangement is depicted in Figure 7.

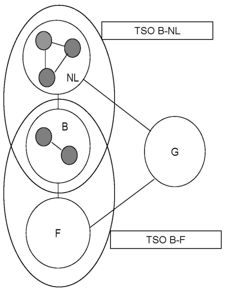

Figure 7: Two bilateral TSOs (F-B) and (B-NL) in the trilateral market

The economic interpretation of this model is that there is a common market for the use of Belgian counter-trading resources by the (F-B) and (B-NL) TSOs, which thus value them at the same price. In contrast there is no common market of interconnection capacities, which TSOs can therefore value differently. Again, this model is a Generalized Nash Equilibrium of the type considered in Sections 4.2.1 and 4.2.2. We want to explore the extent to which access to common counter-trading resources forces coordination among TSOs.

Suppose first that (F-B) and (B-NL) have full and non-discriminatory access to Belgian TSO resources. Numerical simulation shows that we fall back on the solution obtained in Section 6.4.1. Even though we do not explicitly impose coordination of (F-B) and (B-NL) operations, arbitrage on Belgian counter-trading resources implicitly forces this coordination. This result holds true whatever the respective weights given to the two TSOs in the solution of the Generalized Nash Equilibrium. The only solution of the Generalized Nash Equilibrium is the solution of the associated Nash Equilibrium, in this case also the solution of the optimization problem of 6.4.1, that trades interconnections capacities.

Variation limits for (B-NL) TSO	**Total Re-dispatching costs**	**Average Re-dispatching costs**	**Welfare (PX)**
936	454,591,481	0.377904	267,116,140,367
936*0.5	454,591,481	0.377904	267,116,140,367
936*0.1	460,145,326	0.382521	267,110,586,522

Table 3: Welfare, total and average re-dispatching costs of the scenarios where (B-NL) has limited action in Belgium

Suppose next that the access to Belgian counter-trading resources by one of these bilateral TSOs is limited. This asymmetric arrangement is meant to represent one of these heterogeneous organisations that so often prevail in the EU. We now test whether the restriction of arbitrage possibilities limits the implicit coordination. The following reports a sample of the such results. Suppose that (F-B) has full access to the Belgian counter-trading resources, while access to these resources is restricted for (B-NL). Results are reported in Table 3 that is interpreted as follows. The value “936” in the first column corresponds to the largest capacity of the congested lines between Belgium and The Netherlands. It is taken as an upper bound on the amount of counter-trading resources necessary to relieve congestion between Belgium and The

Netherlands. The coefficient that multiplies this value expresses the fraction of this amount of counter-trading resources available to (B-NL). The other columns are self explanatory. The average counter-trading cost is computed by dividing the counter-trading cost by the load of the trilateral market.

Similar outcomes are reported in Table 4 where we consider a symmetric scenario where the (F-B) TSO has limited access to the re-dispatching resources in Belgium. In this case, the value "898" in the first column of the table is the highest capacity of congested lines between France and Belgium.

Variation limits for (F-B) TSO	Total Re-dispatching costs	Average Re-dispatching costs	Welfare (PX)
898	454,592,586	0.377905	267,116,139,261
898*0.5	454,878,412	0.378143	267,115,853,435
898*0.1	656,384,167	0.545655	266,914,347,681

Table 4: Welfare, total and average re-dispatching costs of the scenarios where (F-B) has limited action in Belgium

We observe that reducing the access of either the (F-B) TSO or the (B-NL) TSO to the common Belgian resources increases the re-dispatching cost, thereby causing possibly important decreases of the corresponding social welfare compared to the results of Model 3.1. (267,116,142,245 €). These amount to 5,5 and 202 million € for the cases "936*0.1" and "898*0.1" respectively. This is explained as follows. Constraining the recourse to counter-trading resources for one agent introduces a scarcity rent that adds to the opportunity cost of this agent when it hits its quota. Because prices of counter-trading resources are no longer the same, valuation of the interconnections at opportunity cost is no longer the same and perfect coordination is lost (see Section 4.2.2).

6.4.4 Model 3.4 : Uncoordinated counter-trading with four national TSOs

The situation deteriorates significantly when the four TSOs of Model 3 operate independently. In this last case, depicted in Figure 8, we suppose that counter-trading is run by the purely national TSOs.

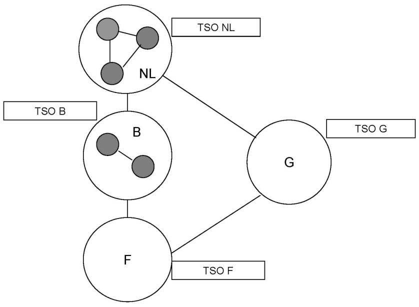

Figure 8: Four national TSOs

We find that this model is infeasible: uncoordinated TSO cannot remove the line overflows created by the clearing of the energy market in market-coupling. The infeasibility comes from the violation of the capacities of four interconnections (Germany and The Netherlands, Belgium and The Netherlands, France and Belgium and France and Belgium). Only an expansion of the network may restore feasibility. In particular, significant increases of the capacity of these lines remove overflows. These additional capacities amount to +40% for the Belgian-French inter-connectors and +200% for the Belgian-Dutch inter-connector.

Notwithstanding these capacity increases, the results obtained with this modified model still reveals a quite inefficient solution. Not counting the cost of capacity additions the social welfare amounts to 264,181,743,898 € (1.1% lower than in Model 1). This is equivalent to a welfare loss of 2.9 billion €/year; a figure that is considerably higher than what was observed before. Moreover, the average re-dispatching cost in The Netherlands is quite high (35.67 €/MWh). In Belgium, this average is lower (4.32 €/MWh), but still higher than the values encountered in the previous scenario. Note that there are no re-dispatching costs in France and in Germany (see Table 5). Congestion problems remain on interconnections and Belgium and The Netherlands where national TSOs handle them at the above mentioned costs.

Re-dispatching costs (€/MWh)			
G	**F**	**B**	**NL**
0.00	0.00	4.32	35.67

Table 5: Average re-dispatching costs

The conclusion of an impossible removal of line overflows by the four TSOs acting independently may look unrealistic. Even if an illustrative case study cannot pretend to realistic data and hence realistic results, most will argue that this outcome is too excessive to be meaningful. We conclude by explaining that it is in fact quite plausible. It should be recalled here that the capacities assumed in the PX model of market-coupling are obtained by simply adding the capacities of the lines. This gives the PX enormous trading possibilities, in fact higher than those that are effectively possible. The results of Models 2 and 3 show that coordinated counter-trading allows one to accommodate this trade, but at a cost. In contrast the absence of cooperation makes counter-trading ineffective. The interpretation of the result if immediate: TSOs offer transmission capacities that are much lower than the real possibilities of the grid. The comparison of this with the other models illustrates how much one sacrifices on energy trading possibilities to allow TSOs to remain independent.

7 Conclusion

These formulations provide different insights into what TSO cooperation can bring to the internal electricity market. The integration of the energy and transmission is the paradigm of efficiency. We also find that MC with an integrated TSO (Model 2) can be reasonably efficient if agents do not take advantage of that separation to game the counter-trading market. Interestingly we also find that multilateral arrangements where different TSOs procure counter-trading resources on the same terms can partially substitute full coordination. This result is attractive but still requires an internal market of counter-trading resources. These should be available to all TSOs without price discrimination or restriction of access. Any limitation of the recourse to these resources, whether resulting from regulatory measures or just pure economics (e.g. the French TSO not resorting to German resources because it is not economic to do so) jeopardizes the coordination result, therefore leading to a more costly counter-trading. The most striking results is the impact of uncoordinated counter-trading. Independent TSOs can only manage the congestion resulting from MC with a drastic increase of network capacities. In practice, this means that independent TSOs effectively manage congestions by drastically restricting the possibilities of the grid compared to what could be done with a more integrated solution.

One should note in closing that we adopted a very optimistic view on counter-trading resources. We supposed that all resources available to the energy markets are also available for counter-trading. This is unrealistic and should be adapted when moving from an academic illustrative study to a real analysis.

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