A Two-Stage Equilibrium Model of the European Cross-Border Trade Regulation

O. Daxhelet Y. Smeers

Abstract— **We present a computable model that encompasses several proposals of the "Florence Regulatory Forum" initiated by the European Commission to deal with cross-border trade. Specifically, the model imbeds both the access to the network and congestion issues analysed by the Forum. Access charges reflect the mechanism devised by the Forum, and congestion at the interconnection is managed through the coordinated auction mechanism recently suggested by the European association of Transmission System Operators. The model allows for various domestic regulations of the less competitive part of market, and different degrees of competition in the more competitive market. We illustrate this flexibility on a stylised but extensive numerical example with the view of showing that the model behaves properly, and identifying policy issues to be studied in a more realistic case study.**

Index Terms— **Cross-Border Trade, Florence Regulatory Forum, Coordinated Auction, Regulation, Two-stage equilibrium, Imperfect Competition.**

I. Introduction

The directive on *common rules for the internal market in electricity* [6] appeared in the Official Journal of the European Union, in January 1997. It constitutes the first serious step of the restructuring of the European electricity sector. The directive had a major impact on the industry but fell short of creating the internal electricity market claimed by European authorities. Additional legislation has recently been introduced to complete the work. An amending directive, adopted in June 2003, strengthened the 1996 law. The regulation on *conditions for access to the network for cross-border exchanges in electricity* [13], hereafter referred to as the regulation, accompanying the amending directive, aims to facilitate the exchanges of electricity among Member States. This paper concentrates on the modelling of some features of the regulation.

The regulation mainly deals with three issues. One is the establishment of a system for accessing the European grid. Congestion management on the interconnections is the second issue. Last but not least, the regulation creates a Regulatory Committee for developing and implementing the rules that govern cross-border trade of electricity in Europe. This latter governance body is a direct outgrowth of the Florence Regulatory Forum, created by the European Commission to help elaborate the regulation [8]. Access and congestion management are treated separately in the regulation. This is also the case in the literature that commonly sees congestion management and tariff for accessing the network as separate subjects. Needless to say both the payments due to congestion management and for accessing the network cumulate and it is their sum that influences the decision of agents operating in the electricity system. A first objective in this work is to cast both problems in a single model and to show that they indeed combine to influence agents' decisions. The governance solution selected in the European process also deserves attention. It indeed appears more and more evident that the integration of electricity systems into a single competitive market mandates strong institutions to organise this competition. The European and US experiences testify that this is not always well perceived, let alone accepted. The resistance against strong institutions may result in weak coordination of market design and operations. This suggests to model the Regulatory Committee as a group of national regulators engaged in a non-cooperative game. Combining the game of the regulators with the market simulation game leads to a two-stage equilibrium problem. The inclusion of governance considerations in the market model is a second objective of this paper.

Our model is a stylised view of the European system but it has several of its main features. New questions must first be looked at through streamlined models and we believe that we make a first step in that direction. The model is also numerically small. Because it is a two-level equilibrium problem, it raises new methodological questions that it is probably also wise to first explore on a prototype. The paper is organised as follows. Section II summarises the principles of access to

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the grid and congestion management set by the regulation. Section III briefly discusses the modelling implications of the directives. Section IV elaborates on the three subjects handled in the regulation. Numerical experiences focusing on the governance problem are presented in section V. Conclusions terminate the paper. Because of space, this paper only gives a brief presentation of the work. The interested reader is referred to [3] for more details.

II. The Regulation

The first proposals for additional electricity legislation go back to March 2001. The European Commission had, at that time, arrived to the conclusion that the enhancement of electricity trade was essential for the introduction of competition in the European electricity system [11]. The regulation proposal, that accompanied the proposal for an amending directive focused on the trade objective. Its aim is to establish common rules that facilitate the cross-border trade of electricity. The European Council reached a common position on these proposals in February 2003. The new laws were eventually approved on 26 June 2003. An extensive discussion of the regulation is provided in [2]. The European association of electricity Transmission System Operators (site `www.etso-net.org`, hereafter referred to as ETSO) and the Council of European Energy Regulators (site `www.ceer-eu.org`, hereafter referred to as CEER) were instrumental in the work leading to this regulation. We briefly describe here the main features of the regulation that we introduce in our model.

A. Access to the European electricity grid

Articles 3 and 4 of the regulation present the principles of access to the grid. Generators and consumers of electricity pay an access charge respectively referred to as the G and L charges. Agents engaged in international trade may also have to pay an export fee (T). The latter must disappear as soon as the G and L charges embed *locational signals*. The regulation sees the locational signals as cost reflective and non-discriminatory. They should also be efficient and induce generators and consumers to adequately locate on the grid. [1] and [2] argue that this goal is at best difficult to achieve. [16] gives a verbal discussion of the issue; [19] presents a more technical analysis of the question. The G and the L charges are meant to cover the cost of the domestic network and differ among Member States. An attempt has been made to at least partially harmonise their relative importance and further work of the Florence Regulatory Forum promises to harmonise those charges altogether. The interesting question is how the Forum will combine the desired harmonisation of the charges with the necessary differentiation of the locational signals. The current G and L and the proposed developments [14] essentially result from cost allocation rules that cannot pretend to any efficiency property. The T component has been modest in the years 2002 and 2003. It disappeared from the 2004 tariff, even though the G and L do not yet reflect any locational signal. It is these cost allocation rules and the mechanisms for computing the T that we imbed in our model.

B. Congestion management

The regulation concentrates on the management of congestion at the interties and leaves the handling of domestic congestion to Member states. This separation of roles is common in European law as it is, to some degree, in federal systems. The argument for separating the two congestion problems is here reinforced by the observation that congestion occurs very infrequently on the grid of the Member States but is almost permanent on the interties. It is reasoned that European law therefore only needs to deal with the management of congestion at the interties. The idea is not new. It led to successes (the Nordic system) and failures (congestion management difficulties in California well before the full meltdown of the system). The regulation and the Florence Regulatory Forum take it that the intra and interzonal separation of the congestion management will work in continental Europe. The discussion therefore mainly concentrated on two zonal approaches. The European Commission favours the market splitting model that has been successfully implemented in the Nordic market. Others, among them ETSO, prefer a coordination auction on the transfer capacities of the interties [14]. ETSO argued that both approaches are strongly related and that market splitting is a particular case of coordinated auction. This is true but hides the fact that the former requires considerable more structuring than the latter. The key difference is that coordinated auction allows for a separation of the energy and transmission markets, while market splitting imposes an integrated energy and transmission markets (see [18] for a discussion of these different positions and the arguments in presence). Our modelling allows for both systems but we restrict the numerical analysis to the coordinated auction. It has the favour of the TSOs, and the European Commission only loosely argues in favour of market splitting. We therefore infer that the coordinated auction will prevail. We briefly describe the approach.

The electricity system of the European Union and Switzerland is seen as a set of control areas, each represented by a notional node where all intra-area injections and withdrawals are supposed to take place. These notional nodes are interconnected by transfer capacities. The set of these nodes and transfer capacities form a virtual electrical network in the sense that its elements are not physical realities but are endowed with electrical properties: lines have a thermal capacity and there exist a DC load flow model of the virtual network. The coordinated auction proposal supposes that agents bid for transmission services between zones. Transmission system operators select the accepted transmission transactions so as to maximise the value of the transfer capacity of the whole virtual network, taking into account its possibilities as represented by its DC model.

The initial proposal for a coordinated auction appeared in [14]. Different papers have since tried to disentangle some of its embedded difficulties. Olmos and Pérez-Arriaga [15] give a formal model of coordinated auction and argue that the method allows one to retain the diversity of organisations prevailing in Europe; they claim that this is indispensable in the current institutional context. They also note that coordinated auction improves on the current uncoordinated auction practice. These arguments contain a lot of truth but are no evidence that the system will work. Two major questions indeed remain. From an electrical point of view, one does not know whether there exists a virtual network that is both compatible with the institutional segmentation of the European system and a reasonable approximation of the physical network. Feasibilities studies are promised that should enlighten the subject. From an economic point of view, there is now a growing consensus that the separation of the energy and transmission systems, which is harmless in a perfect competition world, gives agents more leeway to exert market power in an oligopolistic market. The idea is plausible: there are more instruments to play with when the energy and transmission markets are separated, and each instrument can be used to exert market power. Even if the principle looks obvious, the technicalities are difficult, with the result that we know relatively little on the question. We here adopt the coordinated auction approach without questioning its validity. This assumes both that (i) one can indeed represent the European grid through a politically and physically correct zonal system and that (ii) the separation of the electricity and transmission markets does not induce agents to exert market power via transmission prices. One should note that the French regulator pointed to the probable fallacy of this latter assumption.

III. Modelling implications: the directives.

The first electricity directive left considerable freedom to Member states to establish their national electricity rules. This resulted in a balkanised system that, as the European Commission since recognised, cannot be immediately integrated into a single market. This also creates uneven conditions of competition that should be assessed before the law of unintended consequences damages the system. The aim of our model is to accommodate the integration of this diversity in a prototype model. The following sketches the main features of the model.

A. *Market segmentation*

The market of each Member State is decomposed into competitive and non-competitive segments. This partitioning is similar to the distinction between the eligible and non-eligible markets introduced by the first directive to protect some market segments from competition. The new directive eliminates this distinction and foresees that all consumers be allowed to choose their suppliers in 2007. European experience shows that serious barriers to trade can persist in systems that are, in principle, fully open to competition such as Germany. We take stock of this finding and retain the former segmentation of the market into eligible and non-eligible parts. We simply give it another name (competitive and non-competitive). We also recognise that this distinction is no longer enshrined in law, and hence leave it to the user to select, on the basis of his/her analysis of barriers to trade, what fraction of each national market is effectively open to competition.

The regulation and the accompanying documents of the Regulatory Forum suggest a zonal organisation of the European electricity system. We therefore assume that the price charged to a particular segment of the competitive market can vary with that segment but is uniform in the zone. Similarly the price charged to the non-competitive segment of the market is uniform in a given zone.

Each market segment, competitive and non-competitive, is modelled by a linear demand system where supplies from the different generators are imperfect substitutes. This permits, at least in principle, to represent perceived differences of reliability that could be attached to the generator's supplies. We recognise that such a demand system would be difficult to calibrate.

B. Generation

The first electricity directive removed all exclusive rights in generation and supply in the Member States. This step was effective with the result that there now exist several generators in each Member State. The model therefore allows for a set of generators in each control area (one generator can own plants in different control areas). Generators may supply the competitive segments of all control areas provided they buy transmission services on existing transfer capacities. We combine the removal of exclusive rights with remaining barriers to trade by assuming that several generators can also supply the non-competitive segment but are subject to a different pricing regime (see sections III-C and III-D).

A generator is represented by a quadratic generation cost curve. This allows one to represent increasing short run marginal cost. In most cases (co-generation is an exception) it is relatively easy to calibrate this cost curve on more detailed plant data. The curve also contains a fixed cost. This latter does not play any role in the search for an equilibrium but it allows one to check whether market prices allow generators to cover their fixed charges. Electricity market simulation models indeed generally concentrate on short-run equilibrium. It is essential to assess the extent to which long-run (capacity) costs are covered if one wants to assess (not simulate) long-term equilibrium.

The first electricity directive only required a weak unbundling of transmission from generator. The amending directive is stronger, even though it still refrains from enforcing a full separation of transmission and generation. This results in uneven possibilities for accessing the network. Unbundling is a subject in itself that is not treated here where we assume a total unbundling of generation and transmission in each control area.

C. The competitive market

European power exchanges currently only trade a small fraction of the total electricity produced and consumed in Europe. We neglect the power exchanges in this prototype model and concentrate on the representation of bilateral transactions that constitute the bulk of the market. We accordingly assume that each generator concludes bilateral transactions with customers. Competition in the electricity sector can be intense in low demand period and subject to extreme market power when capacity is tight. The sole, convenient, Cournot paradigm cannot accommodate that diversity of situations. But the introduction of conjectural variation together with the Cournot assumption can. This fix is theoretically adequate. First, there indeed exist a wide variety of mixes of price and quantity competition regimes, that theory alone cannot choose from in market studies. Second, conjectural variation can be used to span this variety of paradigms. There is thus a fundamental indeterminacy in the representation of market power and the user must be called upon to select some assumption. We therefore assume that several generators can supply the competitive segment of the market of each control area. We thus model competition on some market segment through the Cournot assumption, completed with coefficients of conjectural variation. We do not discuss there the calibration of these coefficients of variation.

A generator receives the price paid by the consumer on a given market minus the access charge L. The generator pays an access to the network (G), and possibly an export charge (T). It also pays the congestion charge. This is equivalent to assuming that the total cost paid by the generator is equal to its generation cost plus the sum of all G, L, T and congestion charges implied by its bilateral transaction. One obtains the generator's profit by subtracting this cost from the revenue collected on the different market segments. As discussed in section III, depending on the version of the model, the G, L and T charges are endogenous or exogenous. The congestion charge is always endogenous.

D. The non-competitive market

By definition, barriers to trade limit the supplies to a non-competitive market segment. These parts of the market are thus, more than any other, vulnerable to the exercise of market power. The amending directive mandates an electricity regulator in each Member State and hence removes the German exception that claimed that competition law was sufficient to monitor market power in electricity. It is reasonable to admit that this regulator will intervene if the relative lack of competition leads to excessive prices in those market segments. One can also assume that the threat of the intervention of the regulator may suffice to limit the exercise of market power. France is a case in point. Even though EDF has a strong dominant position in the whole French market, the prices remain comparatively low compared to the rest of Europe without the regulator having to intervene. EDF has market power but does not exercise it – at least not excessively. This puts an implicit bound on the prices in the non-competitive market. What determines these bounds is a difficult matter. But one can make the assumption that the tradition of the member countries will prevail. France will somehow refer to marginal cost, Belgium to average cost, Germany will leave considerable freedom to its generators, possibly limited to a price cap and the Netherlands will be influenced by England and Wales practice. We thus refer to these standard forms of regulation and assume that each non-competitive part of the market is subject to some form of regulation. The model accommodates the standard regulation modes. Specifically we suppose that the price in a non-competitive part of the market can be based on the marginal costs of some supplier of that market, limited by a price cap or be set at monopoly price (absence of an effective regulation). We also suppose that the price can be equal to some average cost. Even if regulators will have less investigation power to compute average cost in the future, one may reasonably assume that a supplier, fearing the threat of regulatory intervention would prepare to show the regulator or competition authorities that it only charges average cost.

IV. Modelling implications: The Regulation

A. Access to the network

A generator located in some zone will pay the zonal G charge to access the network, whether its trade is intra or inter-zonal. Similarly a consumer pays a zonal L charge in order to access the network. The regulation also foresees that generators and consumers engaged in inter-zonal transaction may have to pay an export charge. This charge is meant to compensate the other TSOs for the cost that this transaction imposes on their system. The T charge was set at a low level during the two first years of operation of this tariff. It disappeared from the 2004 tariff and will need to be eliminated when the G and L embed locational signals. The details of the computation of these charges are complex but the underlying principles are simple. The reader is referred to [3] or to the original ETSO papers [14] for the discussion of the details; we limit ourselves here to a brief discussion of the principles.

TSOs divide the transmission network into horizontal and vertical networks. The horizontal network is the "part of the transmission system, which is used to transmit electricity between countries and within the country: it contains the transmission system elements that are influenced significantly by cross-border exchanges". The T charge needs to cover part of the horizontal network costs which is deemed due to transit. The G and L charge are supposed to cover the rest of the horizontal network costs. In [14] ETSO explains that one should aim at measuring the impact of the different transactions on the total cost of the network. The extent to which this can be done is debatable [16]. We here assume that the work has been done and refer to the cost of the transmission network as a function of intra and inter-zonal transactions. We therefore assume a cost function of transmission that consists of a fixed charge and a linear part that depends on these transactions. Failure to find the relation sought by ETSO means that the linear part vanishes and the cost of the network is only represented by a fixed charge.

The G, L and T charges are all based on an allocation of the costs of the network. We adopt the computation of the export tax described by ETSO and for the rest (the most important part consisting of G and L) consider several standard fixed cost allocation procedures. Because of subsidiarity we suppose that different methods can be implemented in different member States.

The construction of these charges suggests two remarks. Except for technicalities related to the computation of imports and exports, cost allocations rules (more generally average cost pricing) boils down to non-linear equalities. These relations are not difficult to specify but they destroy any convexity property of the model. They may generate models that have no solution (when fixed costs are too high) or several solutions. This requires some attention when interpreting the results. Failure to find an equilibrium suggests an error in the fixed charges of the network. It is indeed unlikely that the fixed charges of transmission may be so high as to make the model unfeasible. High G or L values suggest that the model selected to allocate these fixed charges to a small demand, and hence that it chose the wrong equilibrium.

The allocation of the costs of the network also suggests models of different levels of complexity. Suppose first that the cost of the horizontal network boils down to an exogenous fixed charge. This is equivalent to a standard short-term economic problem that simulates the operations of the system within fixed transmission capacities. This suggests two different models. One supposes that one uses past observed flows as an allocation key. This is the simplest model with exogenous G, L and T charges. A more complex problem is to allocate the network costs according to the flows computed by the model. The total cost to allocate is then exogenous, but the G, L and T charges are not. Last, one may also consider a long-term view where the capacities of the horizontal network are endogenous. Both the cost of the horizontal network and the flows used to allocate this costs are then endogenous. This is the most complex model. We model these three different cases. Note that endogenous network cost should, in principle, be accompanied by endogenous generations capacities. This (significant) extension is left for further research.

B. Congestion management

Generators and customers also need to pay a congestion charge. Following ETSO's proposal we supposed that access to the interconnection is ruled by a coordinated auction that allocates the transfer capacities to those that attribute the highest value to it.

The management of congestion through the coordinated auction raises relatively little difficulty once one supposes that the proposed system is indeed viable. We accordingly make the following assumptions. The European grid is modelled as a virtual network that connects zones (notional zonal nodes) through "transfer capacities". The flows on the transfer capacities are obtained from the injections and withdrawals through power distribution factors (PDFs). Transfer capacities are known and non-contingent. The coordinated auction model then boils down to a set of complementarity relations [3] that essentially state that (i) the flows resulting from the zonal injections and withdrawals remain within the transfer capacities, (ii) zone-to-zone transmission prices are obtained from transfer capacity prices very much like in flowgate models and (iii) the price of a transfer capacity can only be different from zero when it is fully used. We further make the assumption that (a) netting is allowed (this assumption can easily be removed to account for the current EU practice), (b) flows that are feasible for the virtual network are also feasible for the real network and (c) agents take the zone-to-zone prices as given and do not take advantage of the separation of the energy and transmission market to further exert market power.

C. The Regulatory Committee

The European law does not foresee any European regulator. It plans instead for a Regulatory Committee that will decide "on guidelines on compensation on transit flows, on harmonisation of national transmission tariffs and on allocation of cross-border interconnection capacity". It is foreseen that national regulators play a crucial role in this Committee. In contrast with directives, a regulation applies as such to all Member States in European law. We mentioned in section II various points where Member States could take advantage of the freedom allowed by directives. We take it for granted that the access system derived from the work of the Forum will be enforceable throughout the EU and make the more heroic assumption that the coordinated auction proposed by ETSO will eventually apply. One parameter is currently left to Member States in the design, namely the allocation of the network costs between the G and L components. This should be harmonised but it is not clear that there will be a unique allocation rule. We consider the choice of this parameter as an example of the decentralised governance of the Regulatory Committee, and model it as a Nash equilibrium where each regulator selects the fixed cost allocation parameters in a way that maximises the welfare of its own constituency, taking the actions of the other regulators as given. We compare this solution to the one where there would be a single EU regulator that maximises the overall welfare of the EU. Because those regulatory actions determine a market between producers and consumers, the overall problem is a two-stage game: regulators decide on the network cost allocation parameters in a first stage taking into account the reaction of the market in the second stage of the game. We thus seek a subgame perfect equilibrium.

V. Sample numerical results

The model has been used first for testing purposes and to explore various issues. We here illustrate two particular questions, both related to the governance of cross-border trade through a Regulatory Committee instead of a EU regulator. The first question has a flavour of case study; the second is more methodological as it relates to the modelling of a system as a two-stage game.

A. Data description

We consider a stylised model comprising four regions. Regions 1 and 2 are comparatively small with respect to regions 3 and 4. In each region r, there is one Transmission System Operator (TSO_r), one or two generation companies (Gen_r), and two customer segments ($Elig_r$ is competitive and accessible to each of the four producers, while $Capt_r$ is partially removed from competition by barriers to trade, and supplied by the local generator(s) only). The four regions are linked together by interconnection capacities. Note that we here assume two generators serving the less competitive markets in regions 3 and 4. The situation is sketched in figure 1. An extensive description of the data, as well as tables and figures illustrating numerical results can be found in [3].

1) Customers Data: Customers $c \in C$ are characterised by a linear demand function. This function is calibrated around a reference point, associating a reference demand level q_0^c to a reference price p_0^c, together with a price elasticity ε^c at that point. The reference values are given in [3].

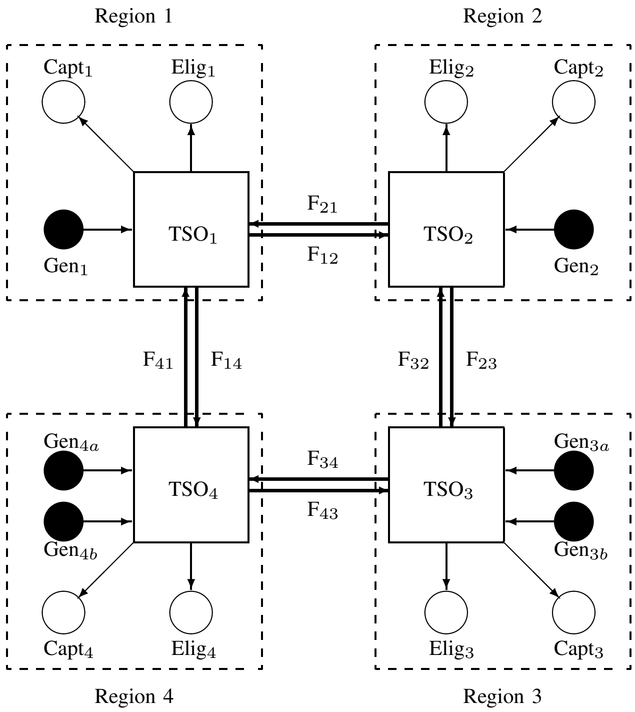

Fig. 1. Stylised model

In order to rebuild the linear demand functions from these parameters, we only need to remember the definition of the price elasticity at the reference point:

$$\varepsilon^c = \frac{p_0}{q_0} \times \frac{\partial q^c}{\partial p^c}_{|(q_0,p_0)} \tag{1}$$

From this equation, we derive the slope of the linear demand function at the reference point and obtain the equation:

$$p^c = p_0^c \left(1 - \frac{1}{\varepsilon^c}\right) - \frac{p_0^c}{\varepsilon^c} q^c \tag{2}$$

where q^c aggregates all supplies q_g^c from generators $g \in G^c$ authorised to provide customer c.

2) Generators Data: Generators $g \in G$ are described by their generation cost function. The latter is given by:

$$CG_g(q_g) = K_g + \sum_{c \in C_g} vc_g^c q_g^c + \tfrac{1}{2} \sum_{c,l \in C_g} q_g^c \omega_g^{c,l} q_g^l \tag{3}$$

We will here make the simplifying assumption that, for a given generator g, the linear variable cost vc_g^c is the same for all its potential customers $c \in C_g$, and that the quadratic part of its costs $\omega_g^{c,l}$ has the same value for each pair (c, l) of customers. Numerical data are provided in [3]

3) Network Data: Network Operators (TSOs) also incur costs. The cost function in region r is assumed to be linear, and given by the expression:

$$NC_r(q) = F^r + \sum_{(g,c) \in T_r} nc_{r,g}^c \times (f_{r,g}^c q_g^c) \tag{4}$$

where T_r is the set of transactions (g, c) affecting region r, F^r denotes the network's fixed cost, and variable transmission costs $nc_{r,g}^c$ are supposed to be small in comparison to generation costs. Moreover, variable transmission costs also depend on the power distribution factors $f_{r,g}^c$ indicating the fraction of a transaction from producer g to customer c which flows through region r. Assumptions on relevant cost information can be found in [3].

Interconnection capacities are limited. We have chosen to implement a bi-directional representation of interconnections, which allows for capacities to be asymmetric. We have introduced an asymmetry on the capacity of the line connecting network areas 1 and 4: the maximum flow from region 4 to region 1 is four times as important as in the opposite direction.

4) The Global Picture of the Model: While some market segments are left to competition (possibly tuned by market power parameters), the less competitive part of the market may be subject to regulation. The envisaged regulations are listed below:

- Profit Maximisation
- Price Cap mechanism
- Cost-Proportional Fully Distributed Costs
- Quantity-based Fully Distributed Costs
- Revenue-based Fully Distributed Costs
- Long Run Incremental Cost

The model has been implemented in GAMS, using CONOPT2 as non-linear solver. Some instances of the model require the DNLP (non-linear model with discontinuous derivatives) version of CONOPT2. This is the case when the costs deemed caused by transit are computed using the first of ETSO's proposal, since this formulation involves a minimum function.

We successively consider the three versions of the model:

- the *Second-Stage Only*, where the parameter defining the repartition of network costs between generators and customers ($0 \leq \lambda_r \leq 1$) is fixed *a priori* to some arbitrary value,
- the *Nash equilibrium*, where each local regulator decides individually on the value of λ_r so as to maximise its local welfare, taking the choice of other regulators as given, and
- the *Cooperative equilibrium*, where the total welfare is maximised by the regulators, regardless of its repartition between agents.

For each of these three assumptions, we consider various combinations of captive market regulation, compensation mechanisms, competitive behaviours, as well as the sensitivity of the obtained solutions to some model parameters.

In this paper we only focus on two specific results of our study. More detailed numerical experience can be found in the full paper [3].

B. Impact of market structure and regulation on the global welfare

"Second-stage only" equilibrium: We first consider the version of the model where the allocation of network costs between generators and customers is fixed to arbitrary values, without any consideration of welfare optimisation. This first version of the model assumes that competition in the competitive markets is represented by a Cournot equilibrium, where each agent is aware of its own impact on prices. Conjectural variation parameters have been introduced in order to provide a more general representation of imperfect competition equilibria. Several pricing rules are envisaged for the less competitive markets: no regulation, price caps, fully distributed costs, long run incremental cost, ...

Welfare evolution according to the regulation of the less competitive market: Quite expectedly, the welfare is most degraded when generators are allowed to practise unrestricted profit maximisation, and is the largest when prices reflect long-run incremental costs. In between, for the different cost allocation methods, welfare increases from revenue-proportional, then cost-proportional, to quantity-proportional allocation. Price cap welfare depends on the level of the cap and might encompass the whole range from the lowest (when caps are so high that it boils down to pure profit maximisation) to the highest (when caps are set equal to long run incremental cost).

Moving to a Nash non-cooperative equilibrium: Allowing the regulators to optimise their local welfare non-cooperatively leads to a Nash equilibrium (if any). Equilibrium prices are barely affected by this move to a two-stage problem. The total welfare is significantly affected by this move, but this results from the fact that we come from some arbitrarily fixed repartition of access charges (between G and L), to a repartition which maximises (in a Nash sense) the regional welfare. The potential improvement therefore depends on the values of the initial arbitrary repartition.

The Compensation Fund, used to reallocate funds among TSOs, is also generally higher at the Nash equilibrium than at the corresponding "second-stage only" equilibrium. The intuitive reasoning therefore is that when each local regulator optimises separately its own welfare, it will try to get the largest possible share from the Compensation Fund. The solution at this equilibrium therefore shows import and export flows which are more important than in the "second-stage only problem".

Moving from Nash to Co-operative equilibrium: Moving one step further towards welfare optimisation, we choose now to look at the total welfare, over all four regions, instead of independently optimising local welfare. We should therefore, in each scenario of regulation of the less competitive market, obtain a total welfare which is greater than (or equal to) the value obtained in the corresponding Nash equilibrium. This may be verified in the numerical results in [3].

Looking at equilibrium prices, however, we see that they are not dramatically modified by this move to a cooperative equilibrium. The main change (with respect to the Nash equilibrium) resides in the repartition of access charges between customers and generators. While regions 3 and 4 are not affected (or very little) by the cooperation of regulators, regions 1 and 2 (the so-called smaller ones) are largely perturbed by this cooperation: in region 1, the access charge passes from 100% on customers to 100% on generators, and in region 2, it goes from roughly from a 70% / 30% repartition in the Nash equilibrium to a 100% on generators in the cooperative equilibrium. The result is that the generator in region 1 looses a considerable amount of profit (depending on the captive market rule) when switching from the Nash to the Cooperative equilibrium, while generator in region 2 increases its profit by roughly the same amount. Profits in regions 3 and 4 do not change significantly.

C. Existence of the Equilibrium

We get interesting variants of the base case by tuning the market power parameters.

We can modify the assumed degree of competition between agents by changing the coefficient of conjectural variation. The latter, denoted with $\xi^c_{g,k}(g \neq k)$ expresses generator g's belief about a competitor k's reaction to a unit change in g's output to customer c (current work in progress [4] provides a more detailed approach of conjectural variations).

In the standard Cournot paradigm, all of these parameters are set to 0 (i.e. all agents believe that competitors will not react to a change in their output). This correspond to the "base case" which served as reference situation in this study.

Setting the conjectural variation parameters to a value of $+1$, for each pair of agents competing on an eligible market, leads to a collusive equilibrium between agents. In the latter case, all equilibrium volumes drop around 50% of the base case level. The end result is also disastrous in terms of welfare which decreases by around 25% with respect to the *base case*.

On the contrary, when set to a negative value, the equilibrium tends towards a price war. Probably because of the difficulty of covering the fixed charges of the network, the model does not find any feasible solution in case of extreme price war (that is, in the Bertrand equilibrium, where $\xi^c_{g,g} = +1$ and $\xi^c_{g,k} < 0$ for $g \neq k$, such that their sum equals -1, see [4] for proofs). But solutions obtained with intermediate values (getting close to this Bertrand limit of -1) show a significant increase in total welfare (above 5%), while prices charged to the competitive customer segments quickly drop towards marginal prices although less competitive customers prices remain at their level.

These situations are interesting and deserve more investigation; they signal conditions where the allocation mechanism hampers the development of competition, in this case by preventing a competitive equilibrium.

We can also play with the generator's awareness of its own impact on market price, by modifying the value of parameter $\xi^c_{g,g}$. When this parameter is set to $+1$, the agent is aware of the impact of its own decisions on market price. When set to 0, it is not aware at all and behaves like a price taker. Again this latter extreme case may lead to infeasible constraints because of the difficulty of covering the fixed costs of the network. In this particular case, a feasible solution can only be achieved with a relaxed version of the problem, where the compensation fund is exogenously set to zero, that is, when no compensation for alleged transit cost is enforced. The increase of welfare is however considerable, since each customer (including captive ones) is now priced at marginal cost. Keeping compensation mechanisms as in the *base case*, we get a feasible solution with values of $\xi^c_{g,g}$ down to 0.15, but cannot go below that value. The welfare increases by almost 25% with respect to the *base case*, and prices on all customer segments drop significantly, also for the captive customer.

VI. Conclusions

We developed a computational framework, destined to encompass the two important issues in Cross-Border Trade: congestion of interconnection capacities, and access to interconnected networks.

The model manages the *congestion* of interconnection capacities through a coordinated auction, where each agent pays the opportunity cost for congested interconnection capacities. Using simplified power distribution factors, the "auction" has been taken as the dual value of using congested interconnection capacities.

Pricing the *access* to interconnected networks does not only involve the coverage of local network costs in areas of injection and delivery, but also transit costs induced on other regional networks through loop flows. We have implemented several combinations of ETSO proposals for compensation mechanisms.

The problem is cast in the form of a game between regional regulators, and is modelled by a two-stage equilibrium problem. In the first stage, regulators decide on the allocation of their regional network costs between generators and customers, taking the consequences of their decisions on the energy market into account. The first-stage game has different versions : either they maximise their regional welfare non-cooperatively (Nash equilibrium), or they centralise the decision as a super-regulator (leading to a cooperative equilibrium).

In the second-stage equilibrium, the consequences of first-stage's decisions are assessed by modelling the energy market as the result of imperfect competition equilibrium on *competitive market* (where competition intensity and market power exercise are modelled through conjectural parameters, ranging from perfect competition to collusion paradigms), coupled with regulated pricing on the domestic *less competitive markets* (ranging from oligopoly pricing to long-run incremental cost pricing, passing by price caps and costs allocation rules). The "rules" that come out of the first-stage game largely influence the final equilibrium.

The total welfare is mainly dependent on the regulation of the less competitive market. However, the repartition of the welfare between the agents (generators and customers) differs considerably, according to the network cost allocation rules selected in the first stage. The distortion of competition that results from this allocation shows up as expected, and welfare increases when one moves from a non-cooperative to a cooperative equilibrium. But the model also reveals questions that deserve more analysis in a realistic case study: some allocation methods foreseen by the compensation mechanism do not necessarily perform as expected. They may reward those deemed to cause transit cost. They may also become inapplicable in extreme conditions. This signals that they may induce undesired effects in non-extreme conditions. In some cases, it appears impossible to find an equilibrium when competition increases too much.

Even though both the compensation methods and allocations of network costs may not influence total welfare much, they drastically influence the allocation of that welfare. This is true whether across control areas or inside each area. Last but not least, the model reveals a close interaction between the access charge and the value of the interconnection. This indicates that these two problems which have been considered separately by the Florence Forum and are commonly seen as distinct issues in the literature may be more interdependent than expected.

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