CAUSAL CONNECTIVITY IN EUROPEAN ELECTRICITY SPOT PRICE DYNAMICS: A NETWORK THEORETICAL APPROACH

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Overview A primary objective of the European Union is to make more stringent the process of electricity market integration across Europe. To this regard, a series of directives – with the last in 2004 – have been transposed into national law, the electricity market liberalization being still in progress in many European countries since then. By using multivariate autoregressive models we have computed the Granger causalities between the electricity prices of 13 European countries during the time frame 2007Q1-2011Q4. The obtained results were modeled as connectivity patterns that illustrate the level of integration between different countries. These graphical models are investigated with mathematical tools from modern network theory, where general connected systems (e.g. social, power grid or brain networks, etc.) are represented by nodes (the units in the system) and links (the relationships) between nodes (Boccaletti et al., 2006). In our model, market integration is represented as the expected number of nodes that are integrated with any other node. The principal advantage of the graph theory approach is that no information is required about individual cross-border transactions. The maximal network integration period was observed between 10/02/2012 to 23/03/2012. Sweden, followed by Denmark and France, exhibits the most highly integrated European electricity spot market. The lowest value, on the other hand, corresponds to the Polish market. Our study shows that the majority of the European electricity spot markets are generally much more cointegrated after the last quarter of 2011. The global (and local) efficencies of the market graph corresponding to this latest period was nearly four times larger compared to the preceding quarter and the entire studied period of time. The dramatic jump of the edge density suggests that there is a trend to the integration of the electricity spot market, which implies that nowadays an increasing number of spot markets significantly affects the behavior of the other markets, with the structure of the market becoming not purely random. On March 3rd , 2011 the Third Liberalisation Package, published on 13/06/2009 and which - by providing binding Framework Guidelines and Network Codes - set the legal framework for cross-border transmission management and market integration, came into force. In other words, the deadline for Member States to implement the Directive 2009/72 concerning common rules for the internal market in electricity was March 3, 2011. Therefore, it might be possible that starting from this period in time some European countries operated a certain form of integration.

Methods The hourly electricity spot prices of 13 European countries - Belgium (BE), Denmark (DM), Finland (FI), France (FR), Germany (DE), Italy (IT), The Netherlands (NE), Norway (NO), Poland (PO), Spain (ES), Sweden (SW), Switzerland (SU), United Kingdom (UK) - were obtained (Thomson Reuters) for the period 02/07/2007 - 29/06/2012, thus implying 31,320 data points for each market. The time-varying directed network was obtained by means of Granger causality as computed with a mixture vector autoregressive (MVAR) model of order 4 over a temporal window of 720 points (30 days). In order to have a time-varying estimation of the network we referred to a sliding window of 4 points, i.e. we estimated a network every 4 hours, resulting in 7,651 total shifts. In mathematics and computer science, graph theory is the study of mathematical structures used to model pair-wise relations between objects from a certain collection. A graph is an abstract representation of a network. It consists of a set of N vertices (or nodes) and a set of L edges (or connections) indicating the presence of some interaction between the vertices. The adjacency matrix A contains the information about the connectivity structure of the graph. When a weighted and directed edge exists from node i to node j, the corresponding entry of the adjacency matrix is $A_{ij} \neq 0$; otherwise $A_{ij} = 0$. The nodal connectivity degree, which is the total number of connections with other vertices, is split into in-degree (representing the integration factor), d_{in}, and out-degree, d_{out}, when directed relationships are being considered. The formulation of the in-degree index d_{in} can be introduced as follows:

$$d_{in}(i) = \sum_{j \in V} a_{i,j} \qquad [1]$$

Equation [1] represents the total amount of links incoming to the vertex i. V is the set of available nodes and a_{ij} indicates the presence of an arc from the point j to the point i. In-degrees have clear functional interpretations.

A large in-degree indicates that a unit is influenced by a large number of other units. Global (E_g) and local efficiencies (E_l) have been also computed as

$$E_g(A) = \frac{1}{N(N-1)} \sum_{i \neq j \in V} \frac{1}{d_{i,j}} \qquad [2]$$

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and

$$E_l(A)=\frac{1}{N}\sum_{i\in V}E_g(A_i) \quad [3]$$

Results Results relative to the network indexes from the period Jul 02, 2007 (01:00:00) – Aug 11, 2007 (00:00:00) (data point 1 on the X-axis) to the period May 21, 2012 (01:00:00) – Jun 30, 2012 (00:00:00) (data point 7,651 on the X-axis) are shown in *Fig.1*, below.

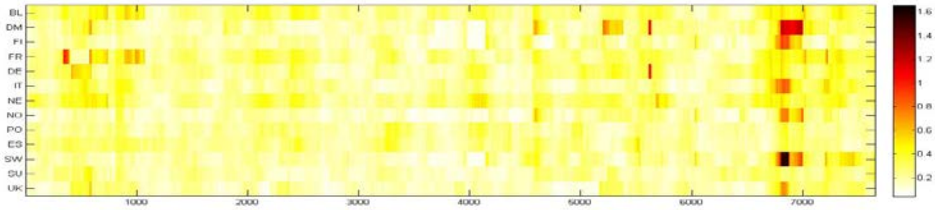

Fig.1 - *In-strength values of the 13 European electricity spot prices by the sliding 4-hour time shifts.*

The maximal network integration period, estimated as the in-degree graph index, was observed between 10/02/2012 to 23/03/2012. Sweden (SW), followed by Denmark (DM) and France (FR), exhibits the most highly integrated European electricity spot market. The lowest value, on the other hand, corresponds to the Polish market. Another period of integration, although less pronounced, is observed between 18/09/2007 to 30/10/2007, for France, and from 04/10/2007 to15/11/2007 for the Dutch market.
The network's global and local efficiencies (Eg and El, respectively) are reported in *Fig.2*, below. The local and global connectivity series are superimposed during the observation period likely due to the relatively low number of data points included in our analysis (though considered a large sample in traditional financial analyses) compared to the very large number of points assumed when working with such techniques.

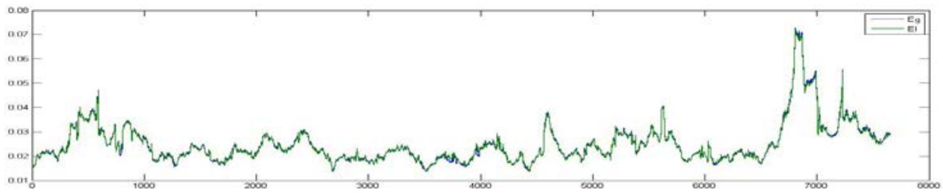

Fig.2 – *The time path of the values for Global (Eg) and local (El) efficiencies for each 4-hour time shift.*

The maximum integration observed is relatively low, with a value of 7.18% (in the period 10/02/2012 to 23/03/2012), corresponding to an increment of nearly 4 times from 1.47% (within the period 19/08/2011 - 30/09/2011).

Conclusions Our study shows that the majority of the European electricity spot markets have achieved a much increased level of global integration efficiency - though still quite moderate lying below the 10 percentage points - following the last quarter of 2011. Even though the edge density of the market graph corresponding to this latest period was nearly four times larger compared to the preceding period. The dramatic jump of the edge density suggests that there is a trend to the integration of European electricity spot markets, implying that an increasing number of spot markets significantly affects each other and that the behavior and structure of the markets becomes more predictable.
It is possible that the liberalization package issued in March 2011 by the EU Commission came into force locally in the majority of the European countries – mainly, Sweden Denmark and France – a few months later. The result of an improved connectivity within the final quarter of 2011 is confirmed by the higher interdependence of EU markets witnessed in terms of increasing volumes of cross-border electricity within European markets (Quarterly Reports on EU Electricity markets, 2011Q4). In addition, in October 2011, abundant rainfalls contributed to extremely low power prices in some areas of the Nordic power market, potentially representing a catalyst for such rise in connections.
Future developments of our work relate to the application of such findings within the context of econometric forecasting models, with the aim of improving the electricity spot price prediction error.

References

1. S. Boccaletti, V. Latora, Y. Moreno, M. Chavez, D.-U. Hwang, 'Complex networks: Structure and dynamics', *Physics Reports* 424 (2006) 175 –308;
2. D. Watts, S. Strogatz, 'Collective Dynamics of Small-World networks', *Nature* 393 (1998), 440-44;
3. V. Latora, M. Marchiori, 'Efficient behavior of small-world networks' *Physical Review Letters* (2001), APS;
4. Market Observatory for Energy, The European Commission, *Quarterly reports on EU Electricity markets* 2011Q4 (2011).