EU ETS Facets in the Net: How Account Types Influence the Structure of the System

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Abstract

In this work, we investigate which countries have been more central during Phases I and II of the European Emission Trading Scheme (EU ETS) with respect to the different types of accounts operating in the system. We borrow a set of centrality measures from Network Theory's tools to describe how the structure of the system has evolved over time and to identify which countries have been in the core or in the periphery of the network. In doing this, we investigate by means of extensive partitions on the different types of accounts and transactions characterizing the EU ETS whether the role of intermediaries (approximated by Person Holding Accounts - PHAs) has affected the overall structure of the system. Preliminary findings over the period 2005-2012 suggest that PHAs have played a prominent role in the transaction of permits, heavily influencing the configuration of the system. This motivates further research on the impact of non-regulated entities in the EU ETS design.

1 Introduction

In the last decade, the European Emission Trading Scheme (henceforth EU ETS) has been the object a heated debate among scholars and policy-makers. Introduced in January 2005, the EU ETS covers 31 countries and more than 11,000 installations from several emission-intensive industry, which account for about 50% of the total European CO2 emissions, and 45% of all GHG emissions. The EU ETS was originally divided in three different phases of increasing length: (i) Phase I: 2005-2007, which was conceived as a learning phase, (ii) Phase II: 2008-2012 and (iii) Phase III: 2013-2020.

Since its implementation in 2005, the EU ETS has attracted much attention for its impressive dimension and record features, being the first transboundary cap-and-trade scheme and the world's largest ETS. In this sense, as argued by Ellerman (2010), the EU ETS can be conceived as the prototype for similar ETS regimes that have been subsequently established in other world regions (California, the Regional Greenhouse Gas Initiative introduced in the Western part of the US, Alberta and Quebec in Canada, Japan, Kazakhstan) and are rapidly spreading worldwide with new emerging schemes projected in many countries, including China, Republic Korea, Brazil and Russia, among the others (World Bank, 2014).

The literature on the EU ETS has been growing very rapidly devoting particular attention to specific aspects or problems encountered by the EU ETS over these years, such as the over-allocation registered in the early phases (Gilbert et al., 2004; Sijm, 2005), the causes, components and consequences of the observed price volatility (Alberola et al., 2008; Chevallier, 2012a; Medina et al., 2014; Gronwald and Hintermann, 2015), the drivers of the price fall in Phase II (Koch et al., 2014), the existence of frauds and monitoring problems (Frunza et al., 2011), the role of banking and borrowing for the functioning of the scheme (Caton et al., 2015; Chevallier, 2012b), the possible carbon leakage effects induced by the EU ETS

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(Clò, 2010: Martin et al., 2014a,b), its estimated impact on emissions abatement (Germà and Stephan, 2015), the structural measures proposed by the European Commission to reform the EU ETS (Clò et al., 2013; de Perthuis and Trotignon, 2014), the perspective of linking the EU ETS with other similar ETSs around the world (Anger, 2008; Tuerk et al., 2009; Ranson and Stavins, 2015). Much of the literature, moreover, has focused on the effects of the EU ETS on technological innovation, using surveys of managerial interviews and/or performing estimations of econometric models that account for the EU ETS among their covariates to test whether the implementation of the system has spurred environmental-friendly innovations (see Abrell et al., 2011; Aghion et al., 2009; Anderson and Di Maria, 2011; Borghesi et al., 2015; Calel and Dechezleprêtre, 2015; Hoffman, 2007; Martin et al., 2011; Rogge et al., 2011; Schmidt et al., 2012).

Despite the vast and ever growing literature on the EU ETS, however, little attention has been paid to the market structure that emerges from the relationships underlying the EU ETS. Very few studies (Jaraite et al. 2013a,b; Betz and Schmidt, 2015; Betz et al. 2015) have performed a detailed analysis of the European data set on the transactions occurring in the EU ETS in order to identify the agents involved in the transactions, their country location, the type of transactions being concluded, the direction of the flows, etc. Among them, Jaraite et al. (2013a and b) provide a detailed description of the ownership situation in the EU ETS in Phase I by mapping individual EU ETS accounts to their Global Ultimate Owner (GUO), that is, to the parent company that owns the accounts. In particular, they focus their analysis on two main types of accounts: Operator Holding Accounts (OHA) that are associated in a 1:1 relationship to each installation regulated under the EU ETS, and Personal Holding Accounts (PHA) that are voluntary accounts used for emission trading by unregulated firms. One account holder can control several OHAs and PHAs in the EU ETS. Moreover, a single parent company can control in turn several account holders. Therefore, by tracing back to the GUO, the analysis performed by the authors helps provide the general framework of the final actors actually involved in the EU ETS market during Phase I.

Betz and Schmidt (2015) investigate the transfer patterns that emerged in the European carbon market during Phase I of the EU ETS. Using cluster analysis, the authors find that most installations regulated by the EU ETS are not or hardly participating in the market; only a small subset of market participants are very active in the EU ETS and they mainly belong to non-regulated companies (e.g. banks). This confirms preliminary results of early studies based on surveys that emphasized the limited participation to the market (Löschel et al., 2010; Löschel, 2011), as well as the initial lack of knowledge of the ETS and its functioning by many regulated companies and the prominent role of the financial sector in acting as "arbitrageur"[1] (Engels et al. 2008; Pinske and Kolk, 2007).

The small number of studies in the literature examining the EU ETS transactions and structure is probably due to the very nature of the data set and to the delay with which data have been released in the past. Today, however, there exist sufficient data to perform a preliminary investigation of the ETS structure which may provide interesting insights on the features of the system and on the possible implications concerning its functioning. For this reason, using a longer data set than the one adopted in previous studies, the present paper intends to examine the evolution that the structure of the EU ETS transactions has had over time. More precisely, building on the evidence on the crucial role of intermediaries in the EU ETS that emerged from previous studies, we aim to evaluate here how the introduction of PHAs may have affected the network of the EU ETS transactions. As Betz and Schmidt (2015) have pointed out, moreover, companies may have strategically chosen the countries in which to open a PHA, therefore it seems important to identify also the country/registry of origin and destination of the transfer patterns being observed. For this reason, in what follows we will apply a network theory approach to represent the system at the national registry level. Hence, one of main advantages of representing the EU ETS as a network

[1] A similar issue was examined also by Trotignon and Delbosc (2008) that provided the very first study based on the EU Community Independent Transaction Log (CITL). The authors point out that the most active players in the market belong to the electricity sector. However, no installation-specific transaction data were available at that time, thus inevitably limiting the scope of their analysis.

relies on the exploitation of centrality measures, based on the structure of the system, to investigate the role played by EU ETS country members. This can provide an innovative aggregate perspective on the EU ETS that allows also to get a deeper insight not only on the trading behaviour of non-regulated participants but also on the role that single States may have played within the EU ETS so far.

The present work differs from the few existing studies mentioned above that examine the European data set in several respects. In the first place, previous contributions focused only on Phase I (the so-called learning phase) of the EU ETS, whereas the present study extends the analysis to a longer period (2005-2012) encompassing both Phase I and Phase II. In the second place, while previous studies (Jaraite et al., 2013; Betz and Schmidt, 2015) focused on the account level that is then aggregated at the parent company level, this work focuses on national registries to assess how member States are connected in the EU ETS and which countries played a central role in the system so far. This feature of our work and the new aggregate perspective that is adopted in this paper lead to a third main distinction with respect to the rest of the literature. Since our focus is at the State level, in fact, differently from other studies we take into account a wider set of transactions, including those types of transactions (Allowance Allocation, Allowance Surrender etc. . .) that involve a government holding account through which allowances are issued and surrendered.

To examine the issues discussed above the structure of the paper will be as follows. Section 2 describes the data set used in the work. Section 3 focuses on the methodology adopted in the analysis, devoting particular attention to the network measures taken into account. Section 4 discusses the main results emerging from the analysis. Section 5 contains some concluding remarks.

2 Data Description

Our data set is drawn from the *European Union Transaction Log*[2] (hereinafter EUTL) and includes transactions occurred between Feb-2005 to Apr-2012. EUTL provides information on: *i)* the date and the type of transaction, *ii)* the identity, the registry and the type of counterparts, and *iii)* the number of transferred permits, among others. The following tables summarise basic descriptive statistics:

Table 1: Descriptive Statistics: Number of Transactions for different Account Types

Account Type (T\A)	***100***	***120***	***121***	***230***	***-1***	**Total**
100	1,592	50,190	7,388	20	39,216	**98,406**
110	493	454	3,838	0	0	**4,785**
120	74,323	14,974	38,444	2,115	25,914	**155,770**
121	3,135	26,646	292,020	877	30,974	**353,652**
-1	16	0	0	0	4,296	**4,312**
Total	**79,559**	**92,264**	**341,690**	**3,012**	**100,400**	**616,925**

Table 1 exhibits the amount of transactions between different types of *transferring* and *acquiring* account counterparts during the reference period, identified by rows and columns codes, respectively. They include the Holding Account (HA, code 100), the Pending Account (PA, code 110), the Operator Holding Account (OHA, code 120) and the Person Holding Account (PHA, code 121). In addition, in *Table 1* code -1 stands for no available info and code 230 indicates a Voluntary Cancellation Account. In particular, *OHA* refers to an account used for trading and compliance purposes which is held by an operator of an installation covered by EU ETS. Each installation is associated with an OHA and many operators of installations can be related to the same parent company. Conversely, PHA represents a voluntary trading account and, even in this case, more than one PHA can belong to

[2]Data are retrieved from http://ec.europa.eu/environment/ets/transaction.do.

the same parent company. Finally, a (Party) HA is a government holding account through which allowances are issued and surrendered. As the table shows, the number of transactions operated by PHA (both as transferring and acquiring counterparts) has largely outweighed those involving OHA and HA, thus confirming the dominant role played by non-regulated actors in the market. Moreover, while PHA performed a similar number of transferring and acquiring transactions (353,652 versus 341,690, respectively), OHA and HA tended to sell permits much more than buy them (the total by rows being much higher than that by column for both codes 100 and 120).

Table 2: Descriptive Statistics: Transaction Types

Transaction Type	# of Transactions	# of Units
10-0	302,104	36,262,809,660
10-1	3,286	76,877,305
10-2	85,691	14,011,050,397
10-24	4	1,011,231
10-26	20	508,510
10-35	123	50,121,034
10-41	20	272,312,173
10-52	271	10,988,828,280
10-53	82,185	16,243,364,175
10-55	8	4,114,611
10-61	128	5,656,535,840
10-92	113	18,619,765
10-93	51	1,316,081
3-0	127,449	11,936,143,966
3-21	15,472	1,009,787,726
Total	**616,925**	**96,533,400,754**
code 10	*474,004*	*83,587,469,062*
code 3	*142,921*	*12,945,931,692*

Table 2 shows the different types of transactions. There are two main partitions: those with code 10 which involve internal transactions (i.e. within the same registry), and those with code 3 which refer to external transactions (i.e. between registries). In particular, internal transactions are decomposed in Internal Transfer (10-0), Allowance Cancellation 2005-2007 (10-1), Allowance Surrender (10-2), Issuance-Internal Transfer Art 63a (10-24), Conversion of Art 63a Allowances (10-26), Allocation of Aviation Allowances (10-35), Cancellation and Replacement (10-41), Allowance Issue 2008-2012 Onwards (10-52), Allowance Allocation (10-53), Correction to Allowances (10-55), Surrendered Allowance Conversion (10-61), Reversal of Allowance Surrender (10-92) and Correction (10-93). Among these[3], Internal Transfer (10-0), Allowance Surrender (10-2) and Allowance Allocation (10-53) are more common in terms of number of transactions, while the other categories are residual. Figures result quite comparable when we consider the number of transferred units, although in this case also code 10-52 (Allowance issue, 2008-2012 onwards) becomes relevant. Finally, code 3-21 refers to External Transfer 2005-2007, while code 3-0 stands for subsequent years transactions. As shown in the table, internal transactions were much more frequent than external ones during the observed period, in terms of both number of transactions (column 2) and number of transferred units (column 3). External transactions, however, represented a very relevant share of total transactions, being equal to 23.2 per cent of the number of transactions and 13.4 per cent of their overall volume.

[3]In particular, as pointed out by Betz and Schmidt (2015), we refer to: *Issuance* when assigned units from Party Holding Accounts are converted into European Union Allowances (EUAs); *Allocation* when EUAs are allocated to an OHA; *Surrendering* when OHAs return EUAs to the Party Holding Account for compliance purposes; *Retirement* whether the EUA identifier is deleted and the corresponding units are transferred into the Party Retirement Account of the reference period; *Cancellation and Replacement* when EUAs are switched from one period into the next compliance period (i.e. the "Banking" practice).

Table 3: Descriptive Statistics: National Registries Time-Coverage

	Acquiring Register	**Transfering Register**
AT	2005-2012	2005-2012
AU	2010-2012	2010-2012
BE	2005-2012	2005-2012
BG	2009-2012	2009-2012
CDM	-	2008-2012
CH	2008-2012	2008-2012
CY	2010-2012	2010-2012
CY0	2006-2008	2006-2008
CZ	2005-2012	2005-2012
DE	2005-2012	2005-2012
DK	2005-2012	2005-2012
EE	2005-2012	2005-2012
ES	2005-2012	2005-2012
EU	2008	2008, 2011
FI	2005-2012	2005-2012
FR	2005-2012	2005-2012
GB	2005-2012	2005-2012
GR	2006-2012	2006-2012
HU	2006-2012	2006-2012
IE	2005-2012	2005-2012
IT	2006-2012	2006-2012
JP	2008-2012	2008-2012
LI	2008-2012	2008-2012
LT	2005-2012	2005-2012
LU	2006-2012	2006-2012
LV	2005-2012	2005-2012
MT	2009-2012	2009-2012
MT0	2007-2008	2007-2008
NL	2005-2012	2005-2012
NO	2008-2012	2009-2012
NZ	2009-2012	2008-2012
PL	2006-2012	2006-2012
PT	2005-2012	2005-2012
RO	2008-2012	2008-2012
RU	-	2011-2012
SE	2005-2012	2005-2012
SI	2005-2012	2005-2012
SK	2005-2012	2005-2012
UA	-	2009-2012

Finally, *Table 3* indicates the periods when the registry codes[4] of the counterparts involved in the transactions are present. As known from the literature (Ellerman, 2010; Clò, 2009; Laing et al. 2014;), European countries joined the programme at different time, although most of them entered the EU ETS between 2005 and 2006. In addition, we can note the presence of no-EU countries (e.g. Australia, Japan, New Zealand and the Russian Federation) as well as the use of the Clean Development Mechanism (CDM) as transferring register from the beginning of Phase II.

3 Methodology

In recent years, complex systems' methodologies have been applied in several fields in order to analyse the features of a system. This literature[5] spreads from the representation of social relationships (e.g. friendships, co-authorships) and economic phenomena (e.g. system risk

[4]We use the same notation reported in the EUTL for transferring (acquiring) registries. Specifically, AT: Austria, AU: Australia, BE: Belgium, BG: Bulgaria, CDM: Clean Development Mechanism, CH: Switzerland, CY (CY0): Cyprus, CZ: Czech Republic, DE: Germany, DK: Denmark, EE: Estonia, ES: Spain, EU: European Commission, FI: Finland, FR: France, GB: United Kingdom, GR: Greece, HU: Hungary, IE: Ireland, IT: Italy, JP: Japan, LI: Liechtenstein, LT: Lithuania, LU: Luxembourg, LV: Latvia, MT (MT0): Malta, NL: Netherlands, NO: Norway, NZ: New Zealand, PL: Poland, PT: Portugal, RO: Romania, RU: Russian Federation, SE: Sweden, SI: Slovenia, SK: Slovakia, UA: Ukraine.

[5]For a deep analysis on Network Theory methodologies and applications, the interested reader can refer to e.g. Jackson (2010) and Newman (2003), among others.

assessment within financial networks) to infrastructure applications (e.g. power grids, internet). The basic ideas behind these studies rely on the description of a system as a graph or network $G = (V, E)$, where V is the set of nodes representing the agents and E is the set of edges which stand for the links (e.g. economic or physical, either directed or not) between pairs of nodes. In particular, in a directed network if i and j are two nodes and there is an edge from i (i.e. source) to j (i.e. target), then this is represented as the pair $(i, j) \in E$, and we say that i is a neighbour of j. Hence, the network is characterised by an adjacency matrix A, where $A_{ij} = 0$ if there is no edge from i to j, while is $A_{ij} = 1$ if such edge exists. Alternatively, a weighted version (W) of the adjacency matrix assigns a weight to each edge.

Formally, in our framework each node i represents a country (represented by the registry code), while the directed edge (i, j) is weighted according to the amount of transferred permits from the transferring country i to the acquiring country j. In order to study how the overall structure of the network has evolved over time, we build a stream of networks one for each month from April 2005 to April 2012[6], thus aggregating transactions on a monthly basis. Since our aim is to investigate the evolution over time of the EU ETS, we prefer to use a monthly frequency to build the networks as the result of the trade-off between data coverage for each registry and aggregating issues. This choice ensures a good availability of transactions for each registry and allows us to describe how the system has changed. In many cases, EUTL provides also information on the identity of the counterparts. However, our work is intended to present a country(registry)-level representation of the EU ETS and, therefore, we decide not to exploit this highly granular level of information[7].

In addition, there are a couple of technical issues affecting the nature of the transactions. Since we are interested in the analysis of how the structure of EU ETS has been affected by changes in the regulatory framework as well as by the spread of financial crisis, we consider several specifications. In particular, we attempt to disentangle the role of the different types of account involved in the transactions, describing how they might have depicted a peculiar picture of the EU ETS market. This is due to the peculiarities of the OHAs, PHAs and HAs whose permits transactions are mainly related to specific activities such as compliance, trading, issuance or surrendering purposes. For these reasons, we provide a description of the EU ETS by focusing on different levels of aggregation of both accounts and transactions types, thus showing e.g. how the introduction of PHAs or HAs (and their related types of transactions) on the OHAs framework may have influenced the structure of system. Below, we summarise these different cases:

- case I: only transactions between OHAs. This case considers operators of an installation covered by the EU ETS which use the account for both trading and compliance purposes.
- case II: only transactions between PHAs. These are voluntary trading accounts in the EU ETS registry.
- case III: OHAs & PHAs. This case involves the two main types of accounts which are present in the EU ETS.
- case IV: OHAs & PHAs & HAs. This case enlarges the operator and person accounts case by adding government accounts through which allowances are issued and surrendered.
- case V: OHAs & PHAs & HAs & PAs & accounts with code -1 (hereinafter, the "*All*" case). This case includes a wide set of operators and, in particular, it is enriched by the presence of transactions between at least one counterpart for which account information is only partially available.

[6]We discard the first two months since there were only few registries operating at that time. In addition, we join together registry codes CY with CY0 and MT with MT0. For the sake of simplicity, we merge non-EU countries plus EU and CDM: this represents the node named *Others*.

[7]Our explorative analysis aims to provide a first introductory insight into the intertemporal evolution of the EU ETS network structure; therefore, we preferred not to build here wider networks with many nodes poorly connected. The exploitation of firm-level information to build networks is left for future research.

Moreover, previous specifications are computed according to two different scenarios. Firstly (scenario a), we consider a parsimonious case where only internal (code 10-0) and external (codes 3-0 and 3-21) transactions are taken into account. Secondly (scenario b), we include also the other types of transactions more frequent in the EU ETS (see *Table 2*), namely: Allowance Surrender (code 10-2), Allowance Issue for 2008-2012 Onwards (code 10-52) and Allowance Allocation (code 10-53). Thus, the first scenario allows us to focus on the impacts of trading activities, either within the same country registry or across registries, while the second scenario provides a more comprehensive picture[8].

3.1 Network Measures

Given a certain network, one may want to disentangle the *importance* of the nodes, thus providing a ranking according to e.g. measures of centrality. The concept of centrality might be translated in more qualitatively meanings such as popularity (e.g. in social networks) or systemic importance (in systemic risk assessment). In our case, more central nodes represent those countries[9] which play a more active role in the EU ETS. For instance, this information might be exploited to evaluate which countries concentrate higher or lower amounts of transferred permits or to analyse the presence of *hubs* in the system which connect two or more geographical areas. In addition, we aim to characterise the structure of the graph by means of common network measures, e.g. the assortativity coefficient, which give useful insights to depict an overall picture of the configuration of the system at a given point in time. Hence, in our investigation strategy we introduce a novel approach based on network properties to study how the EU ETS has evolved over time as a response to changes in the regulatory framework or market conditions. We rely on basic network tools coherently with our introductory goal, although more advanced techniques might easily adopted in future research.

Below we provide a brief overview of the network measures utilised to describe the EU ETS. In particular, given a graph G with N nodes and a weighted adjacency matrix W (with w_{ij} the transferred amount, i.e. the weight, from i to j), then we calculate:

In/Out-Strength. This measures computes the weighted degree of a node. Since the network is directed, we can consider either the amount of weighted edges attaching the node or those departing from that node. These measures are computed as $s_i^{In} = \sum_{j=1}^{N} w_{ji}$ and $s_i^{Out} = \sum_{j=1}^{N} w_{ij}$, respectively. The average In(Out)-Strength of a graph is, therefore, the average of its nodes' In(Out)-Strengths. In addition, the un-weighted versions (i.e. the In/Out Degree) can be computed using the (un-weighted) adjacency matrix A as follows: $k_i^{In} = \sum_{j=1}^{N} a_{ji}$ and $k_i^{Out} = \sum_{j=1}^{N} a_{ij}$, where k_i^{In} (k_i^{Out}) denotes the In(Out)-degree of node i. Finally, s_i and k_i refers to its un-directed version (i.e. simply the Strength and the Degree of node i).
Average Neighborhood In/Out-Strength. It provides the average In(Out)-Strength of the neighborhood of each node. For node i it is computed as $s_i^{Avg} = \frac{1}{s_i} \sum_{j \in H(i)} w_{ij} k_j$, where s_i is the strength of node i, w_{ij} is the weight of the edge from i to j, k_j is the degree of node j and $H(i)$ are the neighbours of i. For directed graphs, previous formula changes according to both source and target nodes.

Degree Centrality. For each node i it computes the fraction of nodes it is connected to. Values are normalized dividing by the maximum possible degree in a simple graph $n-1$, where n is the number of nodes in G. For In(Out)-Degree Centrality we refer to the fraction

[8] A further partition of the EU ETS might involve the unit type (e.g. general allowances, CER, ERU, RMU, tCER, etc.), but this goes beyond the scope of our paper. A brief overview on the number of units for different types is available at *http://ec.europa.eu/environment/ets/registryHoldings.do?search=Search.*

[9] In the paper, the terms country and registry are interchangeable.

of nodes its incoming(outgoing) edges are connected to.

PageRank. This measure computes a ranking of nodes according to the structure of the incoming edges and it is a variation of the eigenvector measure of centrality. In the context of the World Wide Web (where the algorithm was originally developed), the intuition behind this measure is that a page has a high rank not only if its incoming links are many, but also if it has a few highly ranked incoming links. Therefore, to determine the centrality of node i it exploits not only the amount of its incoming links (as approximated for instance by the strength of node i), but it also considers how its neighbourhood is connected to i. This feature makes the *PageRank* an appealing indicator and motivates the exploitation of its variants even in several economic and social fields, such as: financial networks and the assessment of systemic risk (Battiston et al., 2012; Hautsch et al., 2014), social networks (Kwak et al., 2010), multiplex networks (Halu et al., 2013), trade networks (Ermann and Shepelyansky, 2011), urban transportation networks (Agryzkov et al., 2012), the ECommerce (Oestreicher-Singer and Sundararajan, 2012), among others.

The value of the *PageRank* can be defined recursively according to the formula[10]: $PR(i) = \frac{1-d}{N} + d \sum_{j \to i} \frac{PR(j)}{L(j)}$, where $PR(i)$ is the *PageRank* of node i, N is the number of nodes, $L(j)$ is the total amount of links originating from j and the sum is taken over all nodes j having a link to node i. The quantity d ranges between 0 and 1 and represents the impact of a dumping factor which is the probability that a *random surfer* will follow one of the links on the present page. As in the default case, here d is set equal to 0.85.

Assortativity. For non-directed networks, this measure is based on the Pearson correlation between the strength of each pair of nodes. For directed graphs, assortativity coefficients are computed according to both source and target nodes. This means that we compute the correlation between pairs of nodes according to different specifications of their respective amount of inflows or outflows and their combinations.

4 Results and Discussion

We describe the EU ETS according to two different perspectives. Firstly, we investigate which countries have played a central role in the trading of permits. Secondly, we analyse the evolution of the structure of the system by means of how registries are related to each other. In particular, for the first goal we propose a set of centrality measures, i.e. the *In-* and the *Out- Degree centrality* and the *PageRank*, while for second we exploit the *Assortativity coefficient*, i.e. a measure of the correlation between nodes' *In-* or *Out- Strengths*. Finally, estimates are shown for different types of account (e.g. only OHAs or PHAs separately or a wider set of types of account) and for two distinct periods corresponding to the first two phases of the EU ETS program (*Phase I* between 2005-2007 and *Phase II* between 2008-2012). This allows us to depict, and possibly to isolate, the system with respect to the characteristics of the accounts involved in the transactions and according to two different regulatory frameworks.

For instance, in *Figure 1* and *Figure 2* we show the EU ETS networks that emerge from case II (that considers only transactions between PHAs) and case III (that takes both OHAs and PHAs jointly into account). Data refer to traded permits from Apr-2005 to Apr-2012 with transaction type codes equal to 10-0, 3-0 and 3-21. The size of the node is proportional to the in-degree, while the colour is based on the *PageRank* of the node and it ranges from blue (lower values) to red (higher values). Networks are drawn not oriented for representativity purposes. As is shown in the plots, the relationship between in-degree (i.e. the amount of permits acquired by accounts located in that register) and the *PageRank* (i.e. a proxy for the centrality of the node) is not as linear as one could expect. In addition, the inclusion of

[10] For a deep analysis on the computation of the *PageRank* see for instance Berkhin (2005) and Bianchini et al. (2005).

Figure 1: EU ETS network: case II (only transactions between PHAs)

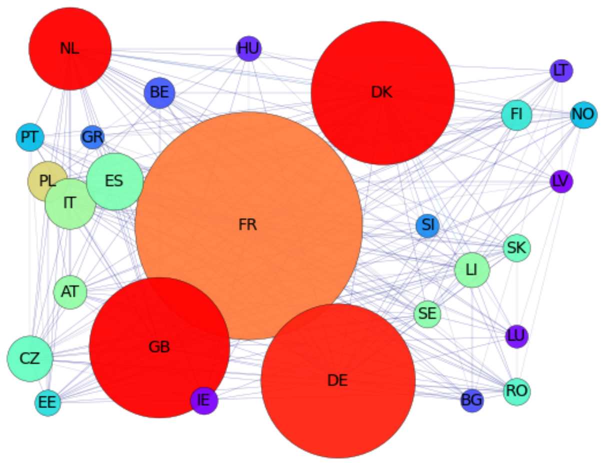
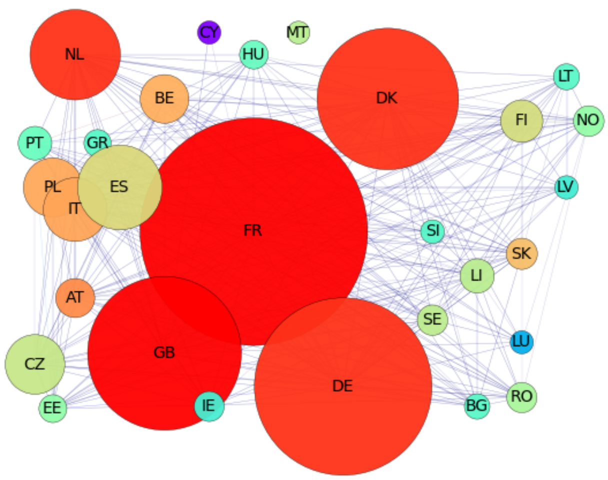


Figure 2: EU ETS network: case III (transactions involving OHAs and PHAs)



different types of account influences the overall configuration.

In *Table 4* we summarise the results of the centrality measures[11]. In the analysis that follows, we will focus on the *PageRank* due to both its novelty in this field and its ability to catch

[11]To save space we report in Appendix A.1 additional measures of centrality: the *in-* and *out- strength* for each node and its *average neighbourhood strength*. Due to the amount of estimates for each month and for each specification we report in Appendix A.1 only a summary for the reference period. Estimates for each month and specification are available from the authors upon request.

non linear effects, although similar investigations can be provided also for the *In-* and *Out-Degree Centrality* measures that are reported in the table. *PageRank* values range from 0 (no central node) to 1 (very central node). In order to replicate the same range, in *Table 4* we report the average of monthly estimates for each phase and specification[12]. Interestingly, preliminary results on the overall average values suggest that although estimates for OHAs and PHAs separately are often quite comparable for the same node, there are some cases where a registry is more central for a certain type of account and less for the other. For instance, over the entire reference period DE is two times more central than the second most central node in the OHAs framework, although in the PHAs case DE is fairly comparable with other registries (DK, FR, GB and NL). Conversely, the latter set of registries (i.e. DK, FR, GB and NL) show opposite patterns and are more central within the PHAs perimeter than in the OHAs case. In addition, it seems that the role of PHAs dominates the other types of account. This might be due to the number and value of transactions which involve PHAs with respect to the other types of account as emerges from *Table 1.* Hence, estimates for OHAs & PHAs turn out to be very near to the ones in the PHAs case. Moreover, the inclusion of the other types of account has a marginal impact since estimates remain comparable with those of the OHAs & PHAs specification. Although this result is not surprising under scenario *a* which considers types of transactions mainly related to the trading of permits, it is interesting to notice that these figures are almost the same even under scenario *b* (see *Appendix A.2*) which involves a more comprehensive set of transactions (e.g. allowance surrender, issue and allocation) and a more active role of the other types of accounts (e.g. HAs). Finally, as regards the two Phases we observe that those registries that were less central in *Phase I* are more likely to remain far from the core of the network also in *Phase II* in every type of account specification. For instance, this is the case of smaller markets (e.g. CY, EE, GR, IE, LT, LU, LV, MT, SI) which usually are not influenced by significant flows of transactions. By contrast, we observe that some registries such as AT, CZ, ES and FR in the OHAs case, and PL, PT and SK in both OHAs and PHAs cases became more central once entered in *Phase II*, while curiously IT (and partially AT, ES and FR) shows opposite behaviours between the two phases under OHAs or PHAs specifications. We can also notice that for each type of account specification the highest values of *PageRank* in *Phase II* are usually below those observed during *Phase I*, thus suggesting the emergence of a more homogeneous system with less clear very central nodes. This might be due to the fact that at the beginning of the EU ETS program some countries were more able to implement trading platforms which facilitated their central position in the trading of permits across countries and operators, while once other registries joined the program the structure of the system became less polarized. This might have weakened the role of some registries as hubs for the trading of permits, although a ranking in the centrality is still present. In addition, the emergence of a more homogeneous system might be partially abscribed also to the entrance into the EU ETS program of new registries during the *Phase II* (e.g. BG, CH, LI, NO, RO, UA and outside Europe registries).

[12]As a technical issue, we make the reasonable assumption that a registry not present in a given month has the respective estimates equal to zero if that registry is present during the corresponding Phase (for simpicity we do not consider the effective month of entrance for each registry since it usually corresponds to the beginning of the Phase). In *Table 4* for each registry we report in bold the weighted average of the estimates for the entire reference period (or only the value of Phase II if that registry is not present in Phase I), where weights are assigned according to the number of months in each Phase.

Table 4: Network Statistics: Measures of Centrality (scenario a)

	In-Degree Centrality					Out-Degree Centrality					PageRank				
	Oha	**Pha**	**Oha & Pha**	**Oha & Pha & Ha**	**All**	**Oha**	**Pha**	**Oha & Pha**	**Oha & Pha & Ha**	**All**	**Oha**	**Pha**	**Oha & Pha**	**Oha & Pha & Ha**	**All**
AT	**0.07**	**0.25**	**0.33**	**0.33**	**0.37**	**0.05**	**0.24**	**0.30**	**0.28**	**0.31**	**0.04**	**0.05**	**0.05**	**0.05**	**0.05**
Phase I	0.03	0.28	0.33	0.32	0.38	0.02	0.28	0.28	0.28	0.33	0.01	0.06	0.05	0.05	0.06
Phase II	0.09	0.22	0.34	0.34	0.36	0.07	0.21	0.31	0.29	0.29	0.06	0.04	0.04	0.04	0.04
BE	**0.11**	**0.06**	**0.20**	**0.20**	**0.20**	**0.11**	**0.07**	**0.24**	**0.22**	**0.22**	**0.05**	**0.02**	**0.03**	**0.03**	**0.03**
Phase I	0.07	0.01	0.13	0.14	0.14	0.06	0.03	0.21	0.21	0.21	0.04	0.01	0.02	0.02	0.02
Phase II	0.13	0.09	0.24	0.24	0.24	0.15	0.09	0.25	0.23	0.23	0.05	0.02	0.04	0.04	0.03
BG	**0.00**	**0.03**	**0.06**	**0.06**	**0.08**	**0.00**	**0.04**	**0.08**	**0.08**	**0.10**	**0.00**	**0.01**	**0.01**	**0.01**	**0.01**
Phase II	0.00	0.03	0.06	0.06	0.08	0.00	0.04	0.08	0.08	0.10	0.00	0.01	0.01	0.01	0.01
CH	**0.00**	**0.00**	**0.00**	**0.23**	**0.23**	**0.00**	**0.00**	**0.00**	**0.35**	**0.34**	**0.00**	**0.00**	**0.00**	**0.03**	**0.03**
Phase II	0.00	0.00	0.00	0.23	0.23	0.00	0.00	0.00	0.35	0.34	0.00	0.00	0.00	0.03	0.03
CY	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Phase I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Phase II	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
CZ	**0.09**	**0.28**	**0.30**	**0.29**	**0.29**	**0.10**	**0.32**	**0.36**	**0.35**	**0.35**	**0.07**	**0.05**	**0.04**	**0.04**	**0.04**
Phase I	0.06	0.26	0.25	0.25	0.25	0.10	0.36	0.35	0.35	0.35	0.03	0.05	0.03	0.03	0.03
Phase II	0.11	0.29	0.33	0.32	0.31	0.10	0.30	0.36	0.35	0.35	0.09	0.05	0.04	0.04	0.04
DE	**0.29**	**0.53**	**0.57**	**0.56**	**0.57**	**0.20**	**0.50**	**0.53**	**0.51**	**0.51**	**0.14**	**0.10**	**0.08**	**0.08**	**0.08**
Phase I	0.40	0.60	0.60	0.59	0.59	0.20	0.55	0.52	0.51	0.51	0.22	0.12	0.10	0.10	0.10
Phase II	0.21	0.49	0.55	0.54	0.55	0.19	0.47	0.54	0.51	0.50	0.09	0.08	0.07	0.07	0.06
DK	**0.08**	**0.51**	**0.57**	**0.56**	**0.57**	**0.08**	**0.47**	**0.47**	**0.45**	**0.45**	**0.06**	**0.10**	**0.08**	**0.08**	**0.08**
Phase I	0.09	0.62	0.70	0.69	0.69	0.09	0.55	0.51	0.51	0.50	0.06	0.15	0.11	0.11	0.11
Phase II	0.08	0.44	0.49	0.48	0.50	0.08	0.42	0.44	0.42	0.42	0.06	0.08	0.07	0.06	0.06
EE	**0.01**	**0.03**	**0.07**	**0.07**	**0.07**	**0.02**	**0.05**	**0.10**	**0.11**	**0.12**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
Phase I	0.02	0.01	0.05	0.05	0.05	0.03	0.02	0.12	0.13	0.13	0.02	0.00	0.01	0.01	0.01
Phase II	0.01	0.05	0.08	0.08	0.08	0.01	0.07	0.09	0.10	0.11	0.01	0.01	0.01	0.01	0.01
ES	**0.12**	**0.30**	**0.33**	**0.34**	**0.34**	**0.12**	**0.25**	**0.32**	**0.32**	**0.31**	**0.07**	**0.06**	**0.05**	**0.05**	**0.05**
Phase I	0.07	0.28	0.30	0.30	0.30	0.08	0.17	0.27	0.27	0.27	0.04	0.07	0.05	0.06	0.05
Phase II	0.16	0.32	0.35	0.36	0.37	0.14	0.30	0.35	0.35	0.35	0.09	0.06	0.05	0.05	0.05
FI	**0.09**	**0.16**	**0.30**	**0.30**	**0.31**	**0.08**	**0.23**	**0.29**	**0.27**	**0.28**	**0.06**	**0.04**	**0.05**	**0.04**	**0.04**
Phase I	0.11	0.19	0.35	0.35	0.35	0.11	0.32	0.36	0.35	0.35	0.07	0.05	0.06	0.06	0.05
Phase II	0.07	0.15	0.27	0.27	0.29	0.06	0.17	0.24	0.23	0.23	0.06	0.03	0.04	0.04	0.04
FR	**0.16**	**0.56**	**0.68**	**0.66**	**0.67**	**0.21**	**0.49**	**0.63**	**0.61**	**0.61**	**0.06**	**0.10**	**0.09**	**0.09**	**0.08**
Phase I	0.14	0.53	0.64	0.63	0.63	0.25	0.42	0.59	0.58	0.58	0.04	0.11	0.09	0.09	0.09
Phase II	0.17	0.58	0.71	0.68	0.69	0.18	0.54	0.65	0.63	0.63	0.08	0.10	0.09	0.08	0.08
GB	**0.17**	**0.64**	**0.74**	**0.73**	**0.74**	**0.17**	**0.56**	**0.61**	**0.61**	**0.62**	**0.06**	**0.12**	**0.11**	**0.10**	**0.10**
Phase I	0.23	0.58	0.70	0.70	0.70	0.18	0.48	0.50	0.50	0.49	0.10	0.12	0.11	0.11	0.11
Phase II	0.13	0.67	0.76	0.75	0.78	0.16	0.61	0.68	0.68	0.70	0.04	0.12	0.10	0.10	0.09
GR	**0.02**	**0.04**	**0.07**	**0.06**	**0.07**	**0.01**	**0.06**	**0.11**	**0.10**	**0.11**	**0.02**	**0.01**	**0.01**	**0.01**	**0.02**
Phase I	0.01	0.00	0.02	0.02	0.04	0.00	0.00	0.02	0.02	0.04	0.00	0.00	0.00	0.00	0.02
Phase II	0.02	0.06	0.10	0.09	0.09	0.02	0.10	0.16	0.15	0.15	0.02	0.01	0.01	0.01	0.02
HU	**0.05**	**0.03**	**0.12**	**0.11**	**0.11**	**0.05**	**0.04**	**0.15**	**0.16**	**0.16**	**0.05**	**0.01**	**0.02**	**0.02**	**0.02**
Phase I	0.06	0.00	0.08	0.07	0.07	0.06	0.01	0.14	0.14	0.14	0.06	0.00	0.01	0.01	0.01
Phase II	0.05	0.05	0.14	0.14	0.14	0.05	0.06	0.16	0.16	0.17	0.05	0.01	0.03	0.02	0.02

Table 4 *(continued)*

	In-Degree Centrality					**Out-Degree Centrality**					**PageRank**				
	Oha	**Pha**	**Oha & Pha**	**Oha & Pha & Ha**	**All**	**Oha**	**Pha**	**Oha & Pha**	**Oha & Pha & Ha**	**All**	**Oha**	**Pha**	**Oha & Pha**	**Oha & Pha & Ha**	**All**
IE	**0.02**	**0.06**	**0.15**	**0.16**	**0.17**	**0.03**	**0.06**	**0.11**	**0.13**	**0.14**	**0.01**	**0.02**	**0.03**	**0.03**	**0.03**
Phase I	0.02	0.02	0.11	0.12	0.12	0.03	0.03	0.07	0.09	0.09	0.01	0.01	0.03	0.03	0.03
Phase II	0.01	0.09	0.18	0.18	0.21	0.02	0.08	0.13	0.15	0.17	0.01	0.02	0.03	0.03	0.03
IT	**0.08**	**0.21**	**0.28**	**0.27**	**0.30**	**0.06**	**0.19**	**0.24**	**0.23**	**0.24**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**
Phase I	0.09	0.09	0.19	0.19	0.19	0.06	0.08	0.15	0.15	0.15	0.07	0.03	0.03	0.03	0.03
Phase II	0.08	0.28	0.34	0.32	0.37	0.05	0.25	0.30	0.28	0.30	0.03	0.06	0.05	0.04	0.04
LI	**0.00**	**0.11**	**0.10**	**0.10**	**0.10**	**0.00**	**0.11**	**0.10**	**0.10**	**0.09**	**0.00**	**0.02**	**0.01**	**0.01**	**0.01**
Phase II	0.00	0.11	0.10	0.10	0.10	0.00	0.11	0.10	0.10	0.09	0.00	0.02	0.01	0.01	0.01
LT	**0.01**	**0.02**	**0.07**	**0.07**	**0.07**	**0.01**	**0.05**	**0.13**	**0.13**	**0.13**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
Phase I	0.01	0.02	0.08	0.08	0.08	0.02	0.05	0.13	0.13	0.13	0.01	0.01	0.01	0.01	0.01
Phase II	0.01	0.01	0.06	0.06	0.06	0.01	0.06	0.12	0.12	0.13	0.01	0.01	0.01	0.01	0.01
LU	**0.00**	**0.03**	**0.03**	**0.05**	**0.05**	**0.01**	**0.01**	**0.03**	**0.03**	**0.03**	**0.00**	**0.01**	**0.01**	**0.01**	**0.01**
Phase I	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.02	0.02	0.00	0.00	0.00	0.01	0.01
Phase II	0.01	0.05	0.05	0.08	0.08	0.01	0.02	0.04	0.04	0.04	0.00	0.01	0.01	0.02	0.02
LV	**0.01**	**0.01**	**0.05**	**0.05**	**0.05**	**0.01**	**0.01**	**0.10**	**0.10**	**0.10**	**0.01**	**0.00**	**0.01**	**0.01**	**0.01**
Phase I	0.02	0.00	0.04	0.05	0.05	0.01	0.01	0.12	0.12	0.12	0.02	0.00	0.01	0.01	0.01
Phase II	0.01	0.02	0.06	0.05	0.06	0.01	0.02	0.09	0.09	0.09	0.01	0.00	0.01	0.01	0.01
MT	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Phase I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Phase II	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NL	**0.10**	**0.51**	**0.61**	**0.62**	**0.64**	**0.11**	**0.50**	**0.53**	**0.53**	**0.54**	**0.04**	**0.09**	**0.09**	**0.08**	**0.08**
Phase I	0.13	0.54	0.63	0.63	0.62	0.17	0.53	0.53	0.52	0.52	0.06	0.11	0.10	0.10	0.09
Phase II	0.09	0.48	0.60	0.61	0.65	0.08	0.49	0.53	0.53	0.55	0.03	0.08	0.08	0.07	0.07
NO	**0.03**	**0.06**	**0.10**	**0.11**	**0.14**	**0.03**	**0.08**	**0.11**	**0.10**	**0.12**	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**
Phase II	0.03	0.06	0.10	0.11	0.14	0.03	0.08	0.11	0.10	0.12	0.01	0.01	0.02	0.02	0.02
Others	**0.00**	**0.00**	**0.00**	**0.14**	**0.14**	**0.00**	**0.00**	**0.00**	**0.12**	**0.32**	**0.00**	**0.00**	**0.00**	**0.02**	**0.02**
Phase II	0.00	0.00	0.00	0.14	0.14	0.00	0.00	0.00	0.12	0.32	0.00	0.00	0.00	0.02	0.02
PL	**0.06**	**0.19**	**0.24**	**0.23**	**0.23**	**0.06**	**0.23**	**0.27**	**0.26**	**0.26**	**0.04**	**0.04**	**0.03**	**0.03**	**0.03**
Phase I	0.04	0.06	0.10	0.10	0.10	0.05	0.13	0.18	0.18	0.18	0.02	0.02	0.02	0.02	0.01
Phase II	0.07	0.27	0.32	0.31	0.31	0.07	0.29	0.32	0.32	0.31	0.06	0.05	0.05	0.04	0.04
PT	**0.06**	**0.09**	**0.15**	**0.14**	**0.14**	**0.07**	**0.09**	**0.19**	**0.18**	**0.18**	**0.04**	**0.02**	**0.03**	**0.02**	**0.02**
Phase I	0.04	0.03	0.10	0.10	0.10	0.05	0.04	0.16	0.16	0.16	0.03	0.01	0.02	0.02	0.02
Phase II	0.07	0.13	0.18	0.17	0.17	0.08	0.12	0.20	0.19	0.19	0.05	0.03	0.03	0.03	0.03
RO	**0.00**	**0.08**	**0.12**	**0.12**	**0.14**	**0.02**	**0.11**	**0.18**	**0.17**	**0.19**	**0.00**	**0.01**	**0.02**	**0.01**	**0.02**
Phase II	0.00	0.08	0.12	0.12	0.14	0.02	0.11	0.18	0.17	0.19	0.00	0.01	0.02	0.01	0.02
SE	**0.06**	**0.15**	**0.21**	**0.22**	**0.25**	**0.09**	**0.15**	**0.23**	**0.24**	**0.26**	**0.04**	**0.04**	**0.03**	**0.03**	**0.04**
Phase I	0.09	0.15	0.20	0.20	0.20	0.13	0.18	0.30	0.30	0.30	0.07	0.04	0.04	0.04	0.04
Phase II	0.05	0.15	0.22	0.23	0.28	0.06	0.14	0.19	0.21	0.23	0.02	0.03	0.03	0.03	0.03
SI	**0.01**	**0.05**	**0.07**	**0.08**	**0.09**	**0.01**	**0.04**	**0.07**	**0.07**	**0.08**	**0.01**	**0.01**	**0.02**	**0.03**	**0.03**
Phase I	0.01	0.02	0.06	0.07	0.07	0.01	0.01	0.03	0.03	0.03	0.01	0.01	0.04	0.05	0.05
Phase II	0.01	0.07	0.08	0.08	0.11	0.02	0.06	0.10	0.09	0.11	0.01	0.01	0.01	0.01	0.02
SK	**0.04**	**0.11**	**0.17**	**0.16**	**0.16**	**0.05**	**0.17**	**0.27**	**0.25**	**0.25**	**0.02**	**0.02**	**0.03**	**0.02**	**0.02**
Phase I	0.02	0.04	0.10	0.10	0.10	0.03	0.11	0.21	0.21	0.21	0.01	0.01	0.02	0.02	0.02
Phase II	0.05	0.16	0.22	0.20	0.20	0.07	0.20	0.31	0.28	0.28	0.03	0.03	0.03	0.03	0.03
UA	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.04**	**0.04**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Phase II	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.00	0.00	0.00	0.00	0.00

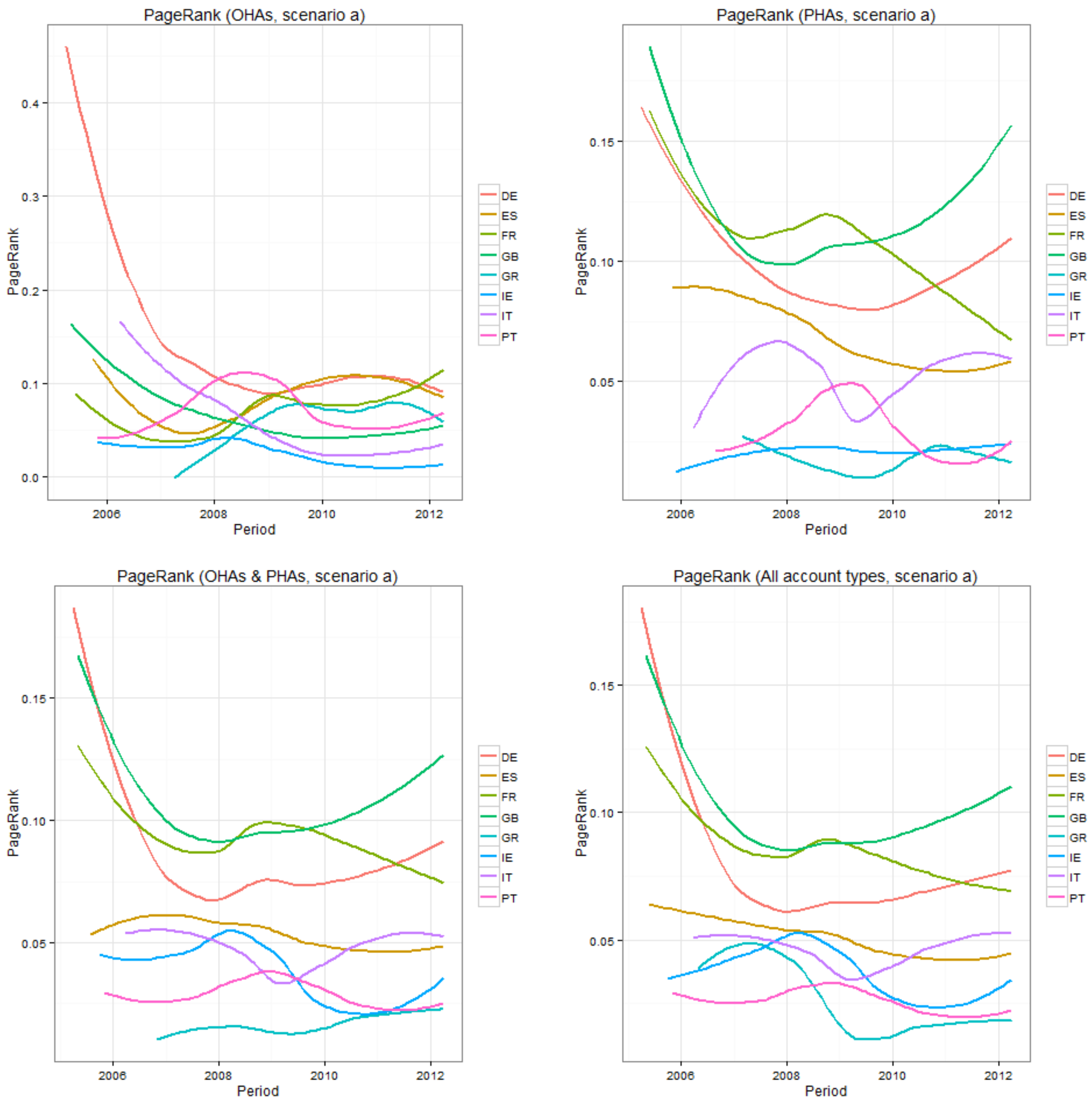
The switch from *Phase I* to *Phase II* coincides also with the outbreak of financial markets. Permits have an embedded financial profile deriving from the fact that the ownership of the rights to use pollutant productions can be traded between accounts and for these purposes specific exchange markets have been established. Therefore, one might be interested in the analysis of how the onset of the financial crisis affected the structure of the EU ETS and influenced the role of each registry. Unfortunately, our data have a limited power which does not allow to disentangle the impact from 2008 onwards of the two different forces: the change of the regulatory framework and the collapse of financial markets. Still, there are some interesting findings that can be observed by splitting our estimates over time according to different types of account. For instance, one can investigate how PHAs, which are more related to trading activities and are usually associated with financial intermediaries, have reacted due to the deteriorated market conditions as well as in response to policy changes.

Below we summarise the behaviour of *PageRanks* along time[13]. The descriptive statistics on centrality measures described before suggest that many registries have played only a marginal role. Therefore, for reasons of clarity, we plot only a set of selected nodes which allows comparisons among different countries. We focus on those countries that have been more prone to suffer from the effects of the global financial crisis and that are usually known as *PIIGS* countries (Portugal, Ireland, Italy, Greece and Spain) and we compare these estimates with countries where investors have proven to be more willing to invest (France, Germany and Great Britain).

In *Figure 3* preliminary results highlight that within OHAs (figure on the top-left in the panel) DE has played a central role during the reference period especially in the early stage of the EU ETS program. Interestingly, we can observe a general decreasing trend until mid 2008, while during *Phase II* patterns are more flattening. There are few exceptions: for instance, PT shows a bell-shaped behaviour across the two phases, while ES and FR exhibit a turning point after 2008 switching from a declining trend into a renewed increasing pattern. Overall, the picture suggests the presence of a much clearer ranking in the centrality measure for *Phase I*, while for *Phase II* estimates of *PageRank* are concentrated in a stricter range of values. In addition, in both phases there is not a neat distinction in *PageRanks* between *PIIGS* countries and the others. Therefore, it seems that at least at the level of operator accounts the impact of the financial crisis as well the change of the regulatory framework did not determine the usual partition of countries related to investors' country risk appetite. Conversely, the PHAs specification depicts a quite different picture (figure on the top-right in the panel). In particular, in this case each country seems to have reacted differently after 2008. For instance, DE, GB and GR show a U-shaped behaviour; ES and FR have a decreasing pattern; PT exhibits even in this case a bell-shaped curve; IE is substantially flat; IT has a peculiar trend resembling an M-shaped curve. In addition, it is worthwhile to notice that in this case there is a clear separation between *PIIGS* countries, characterised by lower values of *PageRanks*, and the others (DE, GB, FR). Therefore, within the PHAs case emerges the presence of a group of countries more active (i.e. more central) than others (i.e. more peripheral) which is in some way coherent with the traditional partition of countries based on the investors' risk perception. Finally, in the PHAs specification DE is not as central as in the case of OHAs, while the higher values of centrality for GB and FR in the PHAs case might be related, for instance, to the fact that financial intermediaries open accounts in these registries due to the presence of dedicated exchange markets. The last two plots (figures on the bottom in the panel) show the combined effects arising from the inclusion of more types of accounts. As expected, the role of PHAs influences the overall representation due to the huge number and volumes of transactions. Therefore, even in these cases we can observe the separation between *PIIGS* countries and the others and we can confirm the same patterns identified for the PHAs specification (with few exceptions, e.g. GR, IE, IT which show slightly different behaviours). Hence, these ranks are unaffected by the enlargement to other types of accounts. Furthermore, scenario *b* (reported in Appendix

[13]Since we are interested in the general tendency of countries' *PageRanks* over time, we plot a smoothed version of the estimates which offers a less erratic representation of countries' trends. In fact, although we use aggregated data on a monthly basis, this is not enough to prevent missing values for some nodes; thus, a fitting procedure helps to overcome this issue. In particular, fitting is done locally in the neighbourhood of each estimate.

Figure 3: PageRanks for different Account Types and Transaction Codes (Scenario a)



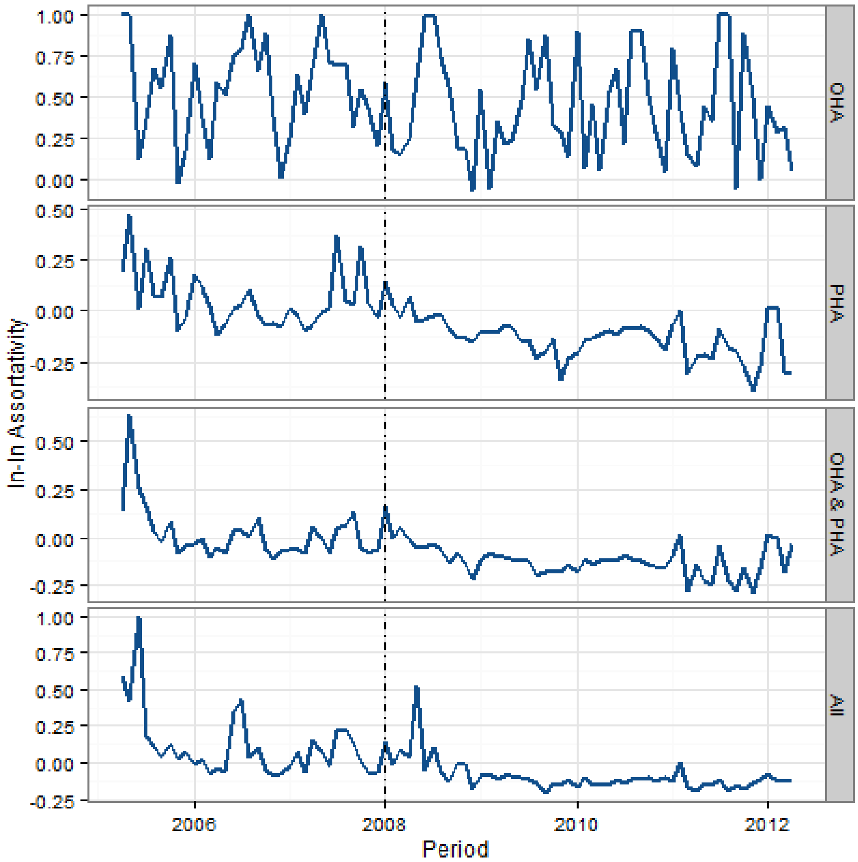
A.3) which introduces a wider set of transactions, including allowances issue, surrender and allocation, still exhibits similar patterns.

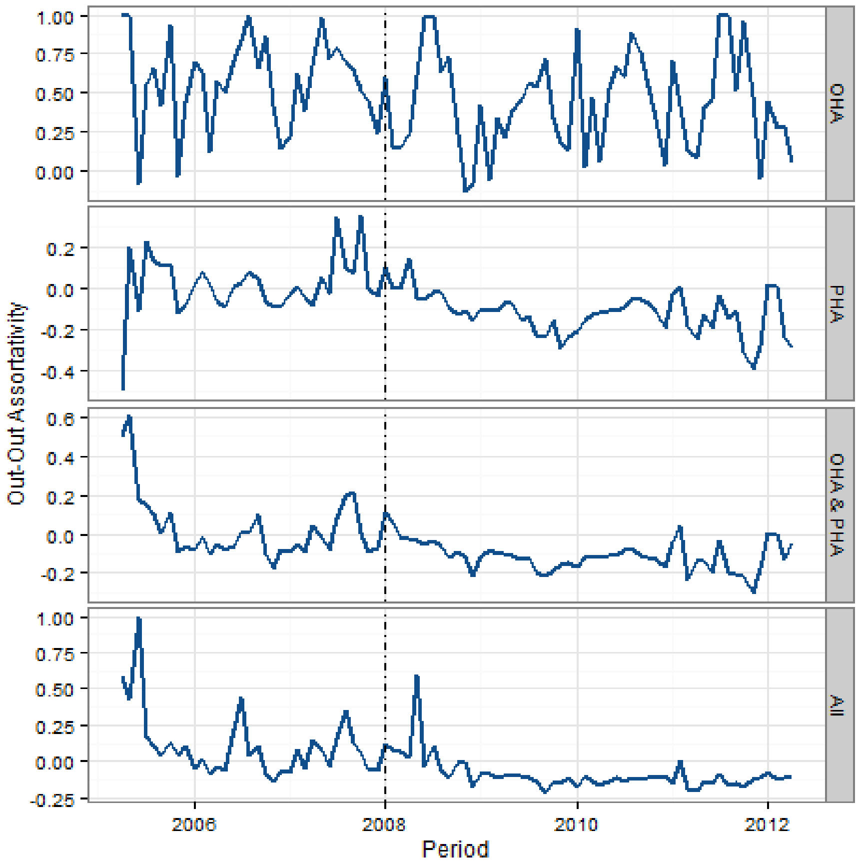
In addition, we consider in *Figure 4* how the *Assortativity* coefficients have evolved over time. This measure indicates how pairs of nodes are related in terms of their strength. Since the network is directed, this determines four possible cases, as a result of combining both source and target nodes with respect to the in-flows or out-flows. For sake of clarity, below we report only the *In-In* and the *Out-Out Assortativity* coefficients for scenario *a*[14]. We focus on the *In-In Assortativity* coefficients, since the *Out-Out Assortativity* coefficients exhibit very similar patterns. In particular, although results for OHAs accounts describe a very volatile framework (first figure in the panel), estimates are basically always positive. This is a sign of a positive relationship between the amount of transactions involving pairs of operators: those that buy (sell) more are likely to be connected to those that buy (sell) more. We also investigate on the presence of a regularity in the up-down pattern related to the end-of-period commitment, but we cannot conclude that this erratic behaviour reflects some specific activities (e.g. allocation or surrendering) or seasonal aspects. Conversely, once we

[14]The interested reader can refer to Appendix A.4 and A.5 for the complete set of figures. Results are basically unaffected by the choice of the different specifications of the *assortativity* coefficient.

analyse the PHAs specification we observe a clear decreasing pattern with a peak around the onset of 2007-08 financial crisis (second figure in the panel). Interestingly, after the collapse of the capital markets the network becomes slightly dis-assortative. Namely, the value of the *Assortative* coefficient becomes negative, which suggests that account holders tended to connect (i.e. exchange permits) with more dissimilar counterparts. This is a remarkable finding since it means that after 2008 PHAs were more prone to trade with other accounts in a more diversified fashion. Since it is not possible to disentangle the effects of the financial crisis and of the changes in the regulatory framework (from *Phase I* to *Phase II*), we can only advance a couple of possible explanations. One is related to risk diversification, which induced PHAs to trade with a wider range of accounts, thus limiting the event of deals with only very similar counterparts. A second explanation, which is partially related to the first, is due to the enlargement of countries' registries in the EU ETS that might have facilitated the exploitation of new markets and exchanges between a wider set of counterparts. Moreover, if we add together OHAs and PHAs, estimates confirm the same change in sign, thus showing a similar pattern as the one for the PHAs specification (third figure in the panel). Even for the *Assortativity* coefficients, the impact of PHAs on the overall picture is, therefore, dominant. Lastly, we consider all the types of account and we obtain a slightly more erratic pattern, but even in this case the trend turns out to be pretty similar to the ones for PHA and OHA & PHA described above (fourth figure in the panel).

Figure 4: Assortativity Coefficients (IN-IN and OUT-OUT) for OHAs, PHAs, OHAs & PHAs and All types of account under scenario a





5 Conclusions

In this work we attempt to describe the EU ETS from a novel perspective borrowed from basic Network Theory techniques. This approach allows us to analyse the structure of the system from a more comprehensive point of view. For instance, in order to investigate which countries are more central one could use a simple computation of the total amount of in-flows or out-flows. Instead we provide measures of centrality which take into account not only the single registry's flows but also the impact of its neighbourhood. In particular, the introduction in this field of measures of eigenvector centrality, by adding non-linear effects, might be useful to enrich the investigation of the key players in the EU ETS. In our analysis, we propose the use of the *PageRank*, which belongs to the eigenvector centrality measures family, to identify which countries have been more central. In addition, since *PageRank* is reaching a growing interest in several fields this might facilitate comparisons with other markets or systems in future research. Furthermore, the structure of the network can be analysed by means of its topological properties. There are many measures in Complex System that can be applied in this field in order to describe the overall structure: for instance, we can introduce tools ranging from basic measures such as the *average Clustering coefficient* or the *Density* of the graph into more sophisticated approaches such as *Community Detection* algorithms. Here, we exploit the *Assortativity* coefficient, since we believe that in this introductory investigation strategy it can be a quite intuitive measure given its similarity with the *Pearson Correlation.*

Furthermore, we analyse a wide set of transactions from Feb-2005 until Apr-2012, thus covering *Phase I* and almost the entire *Phase II.* We should recall that, as reported in the transaction criteria displayed in the *EUTL Transaction Log* website, in "*accordance with Annex XIV (4) of Regulation 389/2013 the information for each completed transaction recorded by the EUTL shall be displayed on 1 May of the third year after the recording of the information*". Thus, we are dealing with the most updated available dataset. In particular, we investigate the structure of the EU ETS from several specifications. Firstly, we distinguish between the different types of account: Holding Account (HA, code 100), the Pending Account (PA, code 110), the Operator Holding Account (OHA, code 120) and the Person Holding Account (PHA, code 121) as well as a set of counterparts for which this information is not reported (indicated in the paper as code -1). Secondly, we propose two different scenarios based on the type of transactions involved in the analysis: scenario a, which is more related to the trading of permits activities (codes 3-0, 3-21 and 10-0), and scenario b which encompasses a more comprehensive set of transactions (adding codes 10-2, 10-52 and 10-53). Therefore, we investigate the structure of the EU ETS by providing a variety of cases in order to disentangle the different roles of the actors involved in this market. Descriptive statistics suggest the emergence of the dominant impact of the PHAs, which are characterised by the significant presence of financial sector intermediaries (Betz and Schmidt, 2015). Thus, transactions were not done for compliance purposes only, but reflected the role of players voluntarily participating in the EU ETS (e.g. banks, financial intermediaries, and brokers). This is a main aspect since the role played by PHAs appears to be dominant in the EU ETS as network analysis seems to confirm. Therefore, further research should try to disentangle the impact of the changes in the regulatory framework (*Phase I* vs. *Phase II*) from the effects of the outbreak of the financial markets which follows the 2007-08 crisis. We attempt to address this issue by providing a comparison of the EU ETS with or without PHAs (for robustness check we also introduce other types of accounts and/or transactions as explained above). In addition, we provide an example which focuses on a classical partition of registries according to investors' country risk appetite. Preliminary findings seem to suggest that the system has reacted to the deteriorated market conditions and policy changes by adopting a more diversified fashion, although some countries (i.e. *PIIGS*) still remain less central in the system.

Finally, we mention some further extensions. Our approach has an introductory goal, since, to the best of our knowledge, this is the first attempt to describe in a very granular way the EU ETS framework by exploiting Network Theory tools. In the future, one could apply the same methodology at installation, firm or parent-company levels, thus showing other perspectives. The methods that we proposed in this work can be easily adapted and enriched.

For instance, this can motivate the analyses on which sectors are more active (central) than others and on how they are related. In addition, this approach could be used to provide a study on the size and regional distributions of the accounts. Furthermore, community detection approaches are highly recommended to identify clusters of players which share similar features. More importantly, a deeper analysis should involve PHAs. Most of them belong to the financial sector and we know that these actors play several fundamental roles in the system, e.g. facilitate the trading of smaller players, provide liquidity to the market and create derivatives instruments to manage market risk. By contrast, financial intermediaries even act as speculative actors to generate profits inducing volatility into the market and this might determine instability for OHAs which trade for compliance purposes. Therefore, to assess the trade-off for financial sector's PHAs inclusion in the EU ETS, the EUTL data should be combined with price data in order to disentangle the role of the different actors involved in the transaction of permits. Moreover, it is unclear how the introduction of new requirements from the Markets in Financial Instruments Directive (MiFID) might have affected the role of financial sector's PHAs. It is, therefore, highly desirable that future research may be able to analyse the combined impacts of the different regulations affecting this field in order to provide useful hints to policy-makers on the optimal mix and design of such regulations.

Finally, the methodology adopted here could be used to analyse the structure of the network that might emerge from possible linking agreements with other ETS in the future, an option that is gaining increasing attention among scholars and policy-makers. In fact, following the decision of California and Quebec to link their own ETS by mutually recognising their allowances, the EU is expected to achieve similar agreements with other ETS in the years to come and negotiations are currently under way with several alternative partners for this purpose. In this regard, Network Theory tools might turn out to be particularly useful to understand the role that single EU Member States might play in a similar new setting and which countries would play a central role in case of linking agreements with different partners.

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A Appendix

For each node, we exhibit the sum of the values of network measures during the reference period (from Apr-2005 to Apr-2012). See the Section *Methodology* for measures' explanations. Given the nature of the transactions involved in scenario b, it is not surprising that estimates for OHAs and PHAs are identical under both scenarios and vary only when other types of account (e.g. Holding accounts or Pending accounts) are considered. Country codes correspond to: AT: Austria, BE: Belgium, BG: Bulgaria, CH: Switzerland, CY: Cyprus, CZ: Czech Republic, DE: Germany, DK: Denmark, EE: Estonia, ES: Spain, FI: Finland, FR: France, GB: United Kingdom, GR: Greece, HU: Hungary, IE: Ireland, IT: Italy, LI: Liechtenstein, LT: Lithuania, LU: Luxembourg, LV: Latvia, MT: Malta, NL: Netherlands, NO: Norway, PL: Poland, PT: Portugal, RO: Romania, SE: Sweden, SI: Slovenia, SK: Slovakia, UA: Ukraine, Others: European Commission & Australia & Japan & New Zealand & Russian Federation & CDM.

A.1 Basic Network Properties

Table 5: Network Statistics: OHAs (scenario a)

	In-Strength	**Out-Strength**	**InIn-Avg Neigh Strength**	**InOut-Avg Neigh Strength**
AT	15,177,693.00	14,487,779.00	545,695.42	161,942.17
BE	97,698,521.00	98,871,628.00	76,482.76	72,227.21
BG	9,500.00	4,272.00	5,373.62	3,582.14
CY	2,153,829.00	2,153,829.00	3.00	3.00
CZ	18,992,704.00	19,939,494.00	1,776,849.73	886,489.47
DE	250,415,029.00	249,128,499.00	20,327.07	218.07
DK	33,887,130.00	33,725,463.00	281,313.72	162,759.38
EE	7,135,598.00	7,270,487.00	150,019.70	90,020.34
ES	230,917,183.00	225,159,737.00	15,721.56	165.00
FI	14,290,902.00	13,358,812.00	28,153.02	128.34
FR	39,462,473.00	42,243,788.00	43,299.02	3,422.51
GB	70,592,426.00	68,570,383.00	3,948,647.63	5,070,186.17
GR	3,862,862.00	3,855,778.00	17.00	17.00
HU	7,170,831.00	7,722,859.00	87,710.34	43,894.06
IE	5,219,368.00	6,603,518.00	4,998,690.51	2,505,994.65
IT	83,610,053.00	82,165,219.00	858,264.27	583,356.48
LT	927,750.00	1,144,150.00	207,108.82	114,062.41
LU	121,840.00	521,840.00	3,710,486.35	1,237,454.51
LV	1,329,379.00	2,122,979.00	1,800,017.78	900,016.39
MT	268,963.00	268,963.00	2.00	2.00
NL	12,741,103.00	13,485,057.00	506,974.42	121,612.13
NO	2,289,019.00	898,654.00	1,031,851.44	626,728.28
PL	24,629,358.00	25,649,045.00	307.83	251.63
PT	10,766,802.00	12,899,266.00	1,402,408.74	325,206.48
RO	1,832,569.00	2,112,559.00	436,626.00	121,083.00
SE	11,103,002.00	11,495,888.00	994,434.24	365,843.35
SI	179,553.00	219,115.00	734,245.85	455,581.42
SK	12,438,137.00	13,144,516.00	467,498.83	227,290.69

Table 6: Network Statistics: PHAs (scenario a)

	In-Strength	**Out-Strength**	**InIn-Avg Neigh Strength**	**InOut-Avg Neigh Strength**
AT	84,711,849.00	91,434,074.00	1,993.69	2,011.00
BE	62,118,852.00	74,098,785.00	65,212,798.30	43,271,498.39
BG	3,484,122.00	3,188,361.00	507,473.96	546,559.05
CZ	218,882,348.00	271,152,802.00	2,636.92	2,300.37
DE	3,259,012,377.00	2,997,591,675.00	790.02	722.60
DK	2,805,474,710.00	2,819,033,541.00	121,070.10	90,874.56
EE	22,608,365.00	24,951,341.00	16,504,218.11	15,263,745.20
ES	387,859,684.00	360,063,063.00	676.64	597.81
FI	59,637,024.00	78,749,788.00	4,852,554.57	2,446,758.52
FR	7,174,833,679.00	7,360,632,016.00	939.69	842.75
GB	2,688,018,109.00	2,611,593,291.00	862.61	808.67
GR	6,301,567.00	22,443,731.00	30,398,194.42	27,159,778.56
HU	17,422,708.00	22,134,339.00	5,482,712.49	4,407,669.88
IE	34,739,589.00	29,835,979.00	6,448,998.83	3,914,916.06
IT	289,930,412.00	317,614,459.00	44,678.39	25,360.56
LI	100,467,865.00	100,366,835.00	571,760.51	643,170.11
LT	1,144,389.00	5,162,802.00	37,800,349.10	35,497,062.44
LU	2,029,628.00	2,407,336.00	1,039,368.22	987,892.49
LV	1,480,921.00	1,911,835.00	3,092,387.22	1,826,017.81
NL	880,990,281.00	853,781,479.00	76,056.06	50,937.35
NO	29,341,690.00	39,332,707.00	55,083,447.52	39,052,182.08
PL	154,488,752.00	162,157,011.00	3,644,317.38	3,559,063.76
PT	37,123,665.00	34,474,030.00	2,512,682.13	1,018,427.38
RO	31,332,514.00	44,135,819.00	24,635,662.13	19,123,530.33
SE	31,491,964.00	51,680,901.00	6,661,901.35	5,952,743.02
SI	5,731,744.00	3,909,144.00	3,078,658.32	2,244,810.71
SK	33,488,888.00	40,310,552.00	6,713,038.28	6,284,145.25

Table 7: Network Statistics: OHAs & PHAs (scenario a)

	In-Strength	**Out-Strength**	**InIn-Avg Neigh Strength**	**InOut-Avg Neigh Strength**
AT	155,916,916.00	146,604,211.00	1,330.35	1,130.21
BE	286,424,184.00	307,371,724.00	20,808,513.41	17,035,300.03
BG	20,995,641.00	33,419,675.00	1,106.86	999.46
CY	4,211,531.00	3,361,839.00	21,127,024.66	19,744,023.33
CZ	468,530,463.00	515,156,320.00	1,000.37	960.91
DE	4,781,823,727.00	4,540,791,655.00	971.68	889.33
DK	3,000,901,290.00	2,991,143,759.00	1,161.14	1,049.78
EE	40,685,921.00	47,317,629.00	47,142,763.52	29,209,888.60
ES	1,029,355,259.00	1,062,015,802.00	622,941.19	374,845.59
FI	197,328,735.00	200,056,741.00	1,121.04	922.24
FR	7,907,589,464.00	7,947,479,640.00	141,194.63	61,073.18
GB	3,569,210,292.00	3,361,588,308.00	1,085.58	902.55
GR	34,696,046.00	67,226,678.00	31,245,886.97	26,988,198.28
HU	47,181,649.00	63,454,508.00	3,678,618.75	2,870,056.13
IE	60,326,997.00	57,743,077.00	106,349.28	91,109.84
IT	547,881,714.00	536,837,141.00	2,152.91	1,749.74
LI	101,467,865.00	103,938,789.00	750,443.39	678,965.62
LT	25,805,677.00	46,562,085.00	28,618,156.46	23,144,800.96
LU	3,145,270.00	5,615,953.00	17,640,602.07	15,203,087.75
LV	5,566,349.00	11,868,303.00	46,237,703.95	35,525,180.96
MT	268,963.00	268,963.00	2.00	2.00
NL	1,161,658,378.00	1,130,735,462.00	1,184.95	1,020.77
NO	65,777,459.00	45,777,039.00	29,690,962.19	19,303,762.11
PL	459,781,738.00	561,721,563.00	6,562,620.09	4,102,953.30
PT	96,532,408.00	117,131,723.00	8,677,865.28	4,727,479.44
RO	62,006,955.00	160,963,662.00	11,742.27	10,389.94
SE	64,589,416.00	84,633,167.00	297,043.84	213,569.45
SI	8,351,549.00	7,172,065.00	4,860,187.50	3,142,583.47
SK	71,667,691.00	121,722,066.00	148,836.38	87,872.52

Table 8: Network Statistics: OHAs & PHAs & HAs (scenario a)

	In-Strength	**Out-Strength**	**InIn-Avg Neigh Strength**	**InOut-Avg Neigh Strength**
AT	246,988,566.00	211,500,953.00	1,323.95	1,164.32
BE	774,387,856.00	790,600,229.00	6,122,678.89	3,570,715.80
BG	98,049,279.00	117,603,415.00	3,627.44	3,058.67
CH	356,021,849.00	536,897,062.00	2,795.44	2,706.98
CY	4,211,531.00	3,451,838.00	24,303,003.66	22,650,004.33
CZ	1,035,370,254.00	1,191,258,270.00	1,151.92	1,099.97
DE	8,981,561,804.00	8,707,806,610.00	1,048.90	947.36
DK	3,143,383,182.00	3,124,057,903.00	992.90	856.16
EE	60,828,588.00	127,878,183.00	119,882,699.89	74,982,399.66
ES	2,947,324,739.00	2,888,580,894.00	622,905.77	374,808.95
FI	237,237,510.00	239,114,259.00	1,043.63	865.69
FR	9,113,187,169.00	9,069,359,758.00	1,241.68	1,121.98
GB	4,715,798,252.00	4,271,948,092.00	1,014.39	867.39
GR	48,672,556.00	81,203,188.00	32,612,191.49	27,132,644.24
HU	139,320,091.00	176,979,821.00	106,284,310.06	96,231,956.68
IE	98,573,949.00	104,848,257.00	1,012.85	896.62
IT	611,695,261.00	589,281,658.00	2,224.01	1,824.60
LI	144,820,884.00	144,453,344.00	100,857,941.38	140,750,753.39
LT	34,355,208.00	88,577,093.00	19,394,673.97	15,734,816.65
LU	36,561,378.00	32,768,406.00	18,035,847.43	15,195,029.83
LV	27,062,609.00	64,096,460.00	43,406,959.16	36,537,318.56
MT	1,230,690.00	1,230,690.00	3.00	3.00
NL	1,637,788,929.00	1,536,395,460.00	1,158.50	1,000.58
NO	72,767,560.00	46,006,858.00	6,005,701.46	5,303,953.91
Others	203,731,481.00	255,085,171.00	1,234.95	1,157.31
PL	1,186,229,557.00	1,307,592,134.00	1,538.21	1,421.94
PT	487,121,947.00	504,164,447.00	8,083,598.89	4,246,815.01
RO	65,068,290.00	168,346,837.00	39,421,996.84	37,346,544.49
SE	71,399,781.00	98,703,012.00	3,491.74	2,845.10
SI	27,531,669.00	25,835,842.00	1,619,325.24	1,283,829.56
SK	225,859,580.00	292,159,820.00	148,013.29	87,316.21
UA	0.00	36,356,035.00	578,511,680.00	520,541,898.00

Table 9: Network Statistics: all types of account (scenario a)

	In-Strength	**Out-Strength**	**InIn-Avg Neigh Strength**	**InOut-Avg Neigh Strength**
AT	278,739,725.00	234,733,818.00	803.67	701.87
BE	774,550,818.00	790,600,229.00	6,122,749.04	3,570,752.07
BG	120,460,476.00	140,014,612.00	3,182.31	2,676.04
CH	356,021,849.00	536,897,062.00	2,970.23	2,857.84
CY	4,211,531.00	3,451,838.00	24,901,003.66	23,248,004.33
CZ	1,035,370,254.00	1,191,258,270.00	1,173.84	1,242.25
DE	9,009,415,884.00	8,707,806,610.00	1,067.69	946.13
DK	3,148,172,412.00	3,124,057,903.00	996.95	844.52
EE	61,058,811.00	128,108,406.00	117,760,964.12	73,535,712.68
ES	2,973,785,690.00	2,888,580,894.00	712,913.05	464,799.72
FI	469,372,033.00	470,615,778.00	987.69	798.06
FR	9,188,761,318.00	9,069,359,758.00	1,255.38	1,117.07
GB	12,565,851,395.00	11,957,452,267.00	1,242.35	1,063.75
GR	83,797,013.00	116,327,645.00	6,619,072.36	5,687,216.19
HU	255,644,146.00	293,303,876.00	88,454,971.09	79,804,868.66
IE	425,976,878.00	430,501,186.00	812.68	777.36
IT	1,378,570,426.00	1,312,975,636.00	951.25	801.68
LI	144,867,187.00	144,453,344.00	29,224.57	38,540.36
LT	34,710,813.00	88,932,698.00	9,775,119.19	7,899,069.36
LU	36,907,879.00	32,768,406.00	18,035,873.40	15,195,038.83
LV	27,419,174.00	64,453,025.00	37,308,713.37	32,991,225.16
MT	1,230,690.00	1,230,690.00	3.00	3.00
NL	4,230,685,473.00	4,092,802,789.00	1,190.99	1,004.20
NO	162,068,683.00	131,263,070.00	4,000,810.39	4,000,633.15
Others	203,731,481.00	670,537,314.00	7,378.41	6,501.73
PL	1,186,229,557.00	1,307,592,134.00	1,562.49	1,439.32
PT	487,189,826.00	504,164,447.00	8,168,638.60	4,251,835.78
RO	131,240,675.00	234,519,222.00	7,666.40	6,839.77
SE	146,847,005.00	153,165,727.00	1,538.56	1,301.33
SI	33,638,027.00	31,942,200.00	687,961.56	625,621.83
SK	225,859,580.00	292,159,820.00	148,147.64	87,434.08
UA	0.00	36,356,035.00	607,812,952.00	538,614,799.00

Table 10: Network Statistics: OHAs (scenario b)

	In-Strength	**Out-Strength**	**InIn-Avg Neigh Strength**	**InOut-Avg Neigh Strength**
AT	15,177,693.00	14,487,779.00	545,695.42	161,942.17
BE	97,698,521.00	98,871,628.00	76,482.76	72,227.21
BG	9,500.00	4,272.00	5,373.62	3,582.14
CY	2,153,829.00	2,153,829.00	3.00	3.00
CZ	18,992,704.00	19,939,494.00	1,776,849.73	886,489.47
DE	250,415,029.00	249,128,499.00	20,327.07	218.07
DK	33,887,130.00	33,725,463.00	281,313.72	162,759.38
EE	7,135,598.00	7,270,487.00	150,019.70	90,020.34
ES	230,917,183.00	225,159,737.00	15,721.56	165.00
FI	14,290,902.00	13,358,812.00	28,153.02	128.34
FR	39,462,473.00	42,243,788.00	43,299.02	3,422.51
GB	70,592,426.00	68,570,383.00	3,948,647.63	5,070,186.17
GR	3,862,862.00	3,855,778.00	17.00	17.00
HU	7,170,831.00	7,722,859.00	87,710.34	43,894.06
IE	5,219,368.00	6,603,518.00	4,998,690.51	2,505,994.65
IT	83,610,053.00	82,165,219.00	858,264.27	583,356.48
LT	927,750.00	1,144,150.00	207,108.82	114,062.41
LU	121,840.00	521,840.00	3,710,486.35	1,237,454.51
LV	1,329,379.00	2,122,979.00	1,800,017.78	900,016.39
MT	268,963.00	268,963.00	2.00	2.00
NL	12,741,103.00	13,485,057.00	506,974.42	121,612.13
NO	2,289,019.00	898,654.00	1,031,851.44	626,728.28
PL	24,629,358.00	25,649,045.00	307.83	251.63
PT	10,766,802.00	12,899,266.00	1,402,408.74	325,206.48
RO	1,832,569.00	2,112,559.00	436,626.00	121,083.00
SE	11,103,002.00	11,495,888.00	994,434.24	365,843.35
SI	179,553.00	219,115.00	734,245.85	455,581.42
SK	12,438,137.00	13,144,516.00	467,498.83	227,290.69

Table 11: Network Statistics: PHAs (scenario b)

	In-Strength	Out-Strength	InIn-Avg Neigh Strength	InOut-Avg Neigh Strength
AT	84,711,849.00	91,434,074.00	1,993.69	2,011.00
BE	62,118,852.00	74,098,785.00	65,212,798.30	43,271,498.39
BG	3,484,122.00	3,188,361.00	507,473.96	546,559.05
CZ	218,882,348.00	271,152,802.00	2,636.92	2,300.37
DE	3,259,012,377.00	2,997,591,675.00	790.02	722.60
DK	2,805,474,710.00	2,819,033,541.00	121,070.10	90,874.56
EE	22,608,365.00	24,951,341.00	16,504,218.11	15,263,745.20
ES	387,859,684.00	360,063,063.00	676.64	597.81
FI	59,637,024.00	78,749,788.00	4,852,554.57	2,446,758.52
FR	7,174,833,679.00	7,360,632,016.00	939.69	842.75
GB	2,688,018,109.00	2,611,593,291.00	862.61	808.67
GR	6,301,567.00	22,443,731.00	30,398,194.42	27,159,778.56
HU	17,422,708.00	22,134,339.00	5,482,712.49	4,407,669.88
IE	34,739,589.00	29,835,979.00	6,448,998.83	3,914,916.06
IT	289,930,412.00	317,614,459.00	44,678.39	25,360.56
LI	100,467,865.00	100,366,835.00	571,760.51	643,170.11
LT	1,144,389.00	5,162,802.00	37,800,349.10	35,497,062.44
LU	2,029,628.00	2,407,336.00	1,039,368.22	987,892.49
LV	1,480,921.00	1,911,835.00	3,092,387.22	1,826,017.81
NL	880,990,281.00	853,781,479.00	76,056.06	50,937.35
NO	29,341,690.00	39,332,707.00	55,083,447.52	39,052,182.08
PL	154,488,752.00	162,157,011.00	3,644,317.38	3,559,063.76
PT	37,123,665.00	34,474,030.00	2,512,682.13	1,018,427.38
RO	31,332,514.00	44,135,819.00	24,635,662.13	19,123,530.33
SE	31,491,964.00	51,680,901.00	6,661,901.35	5,952,743.02
SI	5,731,744.00	3,909,144.00	3,078,658.32	2,244,810.71
SK	33,488,888.00	40,310,552.00	6,713,038.28	6,284,145.25

Table 12: Network Statistics: OHAs & PHAs (scenario b)

	In-Strength	Out-Strength	InIn-Avg Neigh Strength	InOut-Avg Neigh Strength
AT	155,916,916.00	146,604,211.00	1,330.35	1,130.21
BE	286,424,184.00	307,371,724.00	20,808,513.41	17,035,300.03
BG	20,995,641.00	33,419,675.00	1,106.86	999.46
CY	4,211,531.00	3,361,839.00	21,127,024.66	19,744,023.33
CZ	468,530,463.00	515,156,320.00	1,000.37	960.91
DE	4,781,823,727.00	4,540,791,655.00	971.68	889.33
DK	3,000,901,290.00	2,991,143,759.00	1,161.14	1,049.78
EE	40,685,921.00	47,317,629.00	47,142,763.52	29,209,888.60
ES	1,029,355,259.00	1,062,015,802.00	622,941.19	374,845.59
FI	197,328,735.00	200,056,741.00	1,121.04	922.24
FR	7,907,589,464.00	7,947,479,640.00	141,194.63	61,073.18
GB	3,569,210,292.00	3,361,588,308.00	1,085.58	902.55
GR	34,696,046.00	67,226,678.00	31,245,886.97	26,988,198.28
HU	47,181,649.00	63,454,508.00	3,678,618.75	2,870,056.13
IE	60,326,997.00	57,743,077.00	106,349.28	91,109.84
IT	547,881,714.00	536,837,141.00	2,152.91	1,749.74
LI	101,467,865.00	103,938,789.00	750,443.39	678,965.62
LT	25,805,677.00	46,562,085.00	28,618,156.46	23,144,800.96
LU	3,145,270.00	5,615,953.00	17,640,602.07	15,203,087.75
LV	5,566,349.00	11,868,303.00	46,237,703.95	35,525,180.96
MT	268,963.00	268,963.00	2.00	2.00
NL	1,161,658,378.00	1,130,735,462.00	1,184.95	1,020.77
NO	65,777,459.00	45,777,039.00	29,690,962.19	19,303,762.11
PL	459,781,738.00	561,721,563.00	6,562,620.09	4,102,953.30
PT	96,532,408.00	117,131,723.00	8,677,865.28	4,727,479.44
RO	62,006,955.00	160,963,662.00	11,742.27	10,389.94
SE	64,589,416.00	84,633,167.00	297,043.84	213,569.45
SI	8,351,549.00	7,172,065.00	4,860,187.50	3,142,583.47
SK	71,667,691.00	121,722,066.00	148,836.38	87,872.52

Table 13: Network Statistics: OHAs & PHAs & HAs (scenario b)

	In-Strength	**Out-Strength**	**InIn-Avg Neigh Strength**	**InOut-Avg Neigh Strength**
AT	654,354,100.00	618,866,487.00	1,336.10	1,172.63
BE	1,313,165,755.00	1,329,378,128.00	6,122,471.81	3,570,556.21
BG	98,049,279.00	117,603,415.00	3,627.44	3,058.67
CH	356,021,849.00	536,897,062.00	2,795.47	2,707.02
CY	52,923,569.00	52,163,876.00	15,173,015.53	14,170,018.82
CZ	2,837,469,104.00	2,993,357,120.00	1,076.39	1,035.76
DE	13,723,868,286.00	13,450,113,092.00	1,039.06	941.49
DK	3,386,824,496.00	3,367,499,217.00	992.26	856.52
EE	196,833,862.00	263,883,457.00	115,756,265.94	72,231,379.81
ES	4,548,794,829.00	4,490,050,984.00	878.78	794.94
FI	593,701,345.00	595,578,094.00	1,014.35	842.34
FR	11,869,469,807.00	11,825,642,396.00	1,241.39	1,124.12
GB	6,092,740,409.00	5,648,890,249.00	1,010.85	863.35
GR	956,016,213.00	988,546,845.00	29,630,188.93	24,481,964.99
HU	377,045,338.00	414,705,068.00	106,283,968.14	96,231,645.29
IE	222,024,113.00	228,298,421.00	991.74	868.26
IT	1,909,148,890.00	1,886,735,287.00	2,222.16	1,824.81
LI	145,036,918.00	144,669,378.00	56,899.54	79,073.32
LT	105,620,933.00	159,842,818.00	19,394,075.44	15,734,362.57
LU	62,718,355.00	58,925,383.00	13,660,896.09	11,093,510.23
LV	56,530,122.00	93,563,973.00	39,919,443.46	33,536,051.91
MT	21,479,123.00	21,479,123.00	9.00	9.00
NL	2,048,748,155.00	1,947,354,686.00	1,157.62	1,000.36
NO	72,767,560.00	46,006,858.00	6,005,701.46	5,303,953.91
Others	203,731,481.00	255,085,171.00	1,234.95	1,157.31
PL	5,376,431,711.00	5,497,794,288.00	948.50	963.79
PT	806,071,761.00	823,114,261.00	8,082,471.92	4,245,900.73
RO	209,115,768.00	312,394,315.00	39,422,000.02	37,346,544.39
SE	179,210,788.00	206,514,019.00	3,350.40	2,736.20
SI	80,207,516.00	78,511,689.00	1,619,317.24	1,283,820.07
SK	841,874,145.00	908,174,385.00	145,657.41	85,603.08
UA	0.00	36,356,035.00	578,511,680.00	520,541,898.00

Table 14: Network Statistics: all types of account (scenario b)

	In-Strength	**Out-Strength**	**InIn-Avg Neigh Strength**	**InOut-Avg Neigh Strength**
AT	940,888,993.00	896,883,086.00	796.26	693.20
BE	1,888,325,561.00	1,904,374,972.00	6,122,489.27	3,570,546.41
BG	652,711,818.00	672,265,954.00	3,057.29	2,577.98
CH	356,021,849.00	536,897,062.00	2,970.28	2,857.89
CY	74,036,055.00	73,276,362.00	13,521,019.13	12,788,022.95
CZ	2,837,469,104.00	2,993,357,120.00	1,096.41	1,153.46
DE	17,999,115,195.00	17,697,505,921.00	1,057.37	941.74
DK	3,658,554,357.00	3,634,439,848.00	1,001.47	852.76
EE	341,637,560.00	408,687,155.00	113,633,904.59	70,783,807.52
ES	6,260,726,712.00	6,175,521,916.00	871.01	770.36
FI	1,237,226,877.00	1,238,470,622.00	944.37	759.82
FR	11,945,043,956.00	11,825,642,396.00	1,254.98	1,119.11
GB	17,222,691,624.00	16,614,292,496.00	1,249.24	1,068.62
GR	1,418,535,474.00	1,451,066,106.00	3,504,151.55	2,903,623.90
HU	776,055,785.00	813,715,515.00	88,453,979.35	79,803,818.91
IE	835,805,492.00	840,329,800.00	723.32	676.73
IT	5,464,243,982.00	5,398,649,192.00	912.36	766.62
LI	145,083,221.00	144,669,378.00	20,787.79	27,325.34
LT	194,492,977.00	248,714,862.00	9,774,006.13	7,898,204.82
LU	90,432,076.00	86,292,603.00	13,660,915.01	11,093,513.90
LV	112,970,497.00	150,004,348.00	33,820,436.31	29,989,084.23
MT	32,194,428.00	32,194,428.00	11.00	11.00
NL	5,829,386,124.00	5,691,503,440.00	1,207.06	1,017.69
NO	353,987,978.00	323,182,365.00	4,000,815.50	4,000,634.40
Others	203,731,481.00	670,537,314.00	7,378.42	6,501.74
PL	5,376,431,711.00	5,497,794,288.00	968.05	977.49
PT	1,169,597,404.00	1,186,572,025.00	6,692,225.46	3,275,671.44
RO	1,221,206,685.00	1,324,485,232.00	1,362.48	1,199.31
SE	557,798,044.00	564,116,766.00	1,350.87	1,150.90
SI	201,926,444.00	200,230,617.00	37,904.13	25,571.26
SK	841,874,145.00	908,174,385.00	145,707.33	85,640.65
UA	0.00	36,356,035.00	607,812,952.00	538,614,799.00

A.2 Measures of centrality under scenario *b*

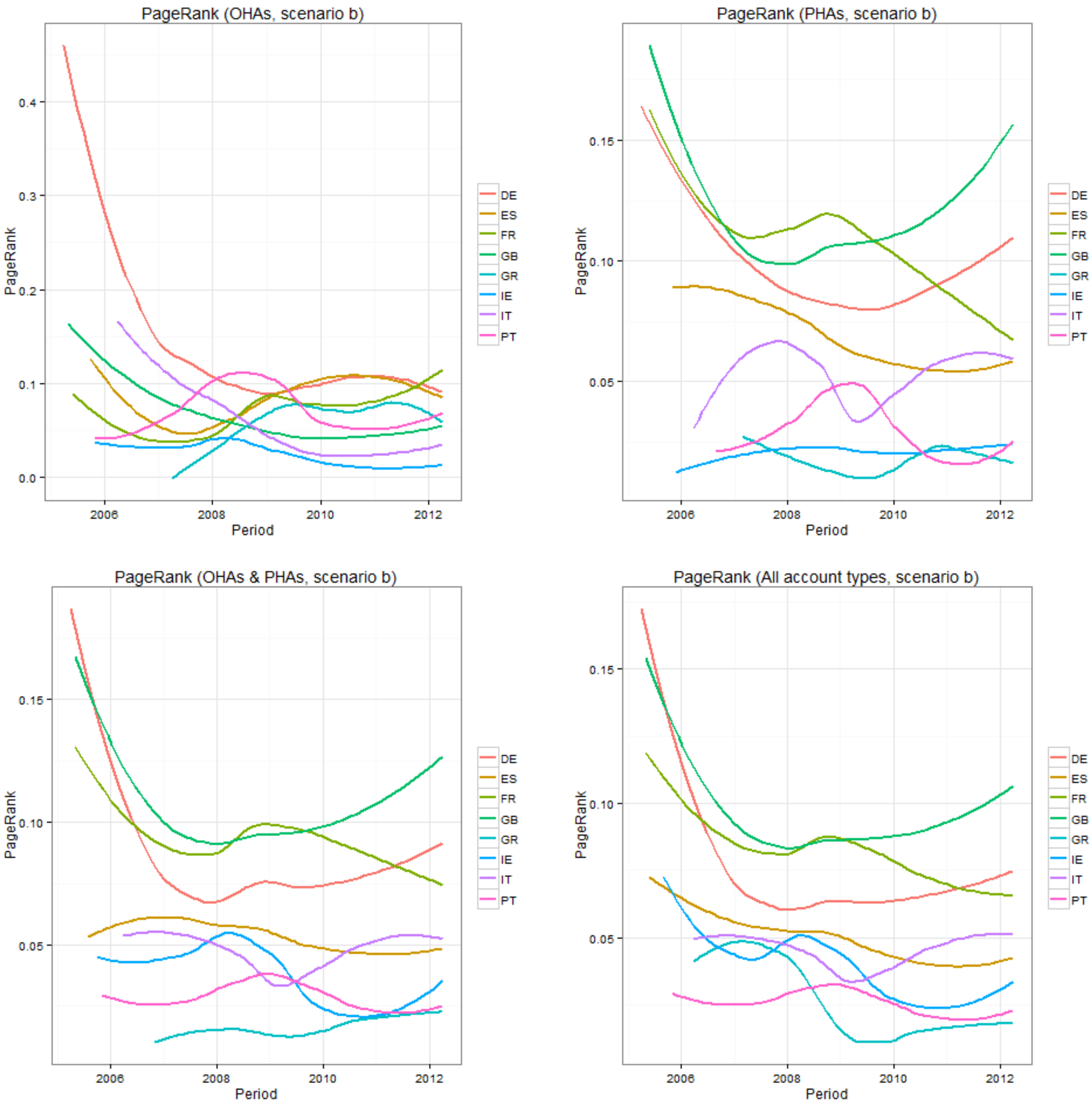
	In-Degree Centrality					Out-Degree Centrality					PageRank				
	Oha	Pha	Oha & Pha	Oha & Pha & Ha	All	Oha	Pha	Oha & Pha	Oha & Pha & Ha	All	Oha	Pha	Oha & Pha	Oha & Pha & Ha	All
AT	**0.07**	**0.25**	**0.33**	**0.33**	**0.37**	**0.05**	**0.24**	**0.30**	**0.28**	**0.31**	**0.04**	**0.05**	**0.05**	**0.05**	**0.05**
Phase I	0.03	0.28	0.33	0.32	0.37	0.02	0.28	0.28	0.27	0.33	0.01	0.06	0.05	0.05	0.06
Phase II	0.09	0.22	0.34	0.34	0.36	0.07	0.21	0.31	0.29	0.29	0.06	0.04	0.04	0.04	0.04
BE	**0.11**	**0.06**	**0.20**	**0.20**	**0.20**	**0.11**	**0.07**	**0.24**	**0.22**	**0.22**	**0.05**	**0.02**	**0.03**	**0.03**	**0.03**
Phase I	0.07	0.01	0.13	0.14	0.14	0.06	0.03	0.21	0.21	0.21	0.04	0.01	0.02	0.02	0.02
Phase II	0.13	0.09	0.24	0.23	0.24	0.15	0.09	0.25	0.23	0.23	0.05	0.02	0.04	0.03	0.03
BG	**0.00**	**0.03**	**0.06**	**0.06**	**0.08**	**0.00**	**0.04**	**0.08**	**0.08**	**0.09**	**0.00**	**0.01**	**0.01**	**0.01**	**0.01**
Phase II	0.00	0.03	0.06	0.06	0.08	0.00	0.04	0.08	0.08	0.09	0.00	0.01	0.01	0.01	0.01
CH	**0.00**	**0.00**	**0.00**	**0.23**	**0.22**	**0.00**	**0.00**	**0.00**	**0.34**	**0.34**	**0.00**	**0.00**	**0.00**	**0.03**	**0.03**
Phase II	0.00	0.00	0.00	0.23	0.22	0.00	0.00	0.00	0.34	0.34	0.00	0.00	0.00	0.03	0.03
CY	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.00**	**0.00**	**0.01**	**0.01**	**0.01**	**0.00**	**0.00**	**0.00**	**0.01**	**0.00**
Phase I	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Phase II	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01
CZ	**0.09**	**0.28**	**0.30**	**0.29**	**0.28**	**0.10**	**0.32**	**0.36**	**0.35**	**0.34**	**0.07**	**0.05**	**0.04**	**0.04**	**0.03**
Phase I	0.06	0.26	0.25	0.25	0.25	0.10	0.36	0.35	0.34	0.34	0.03	0.05	0.03	0.03	0.03
Phase II	0.11	0.29	0.33	0.32	0.31	0.10	0.30	0.36	0.35	0.35	0.09	0.05	0.04	0.04	0.04
DE	**0.29**	**0.53**	**0.57**	**0.55**	**0.55**	**0.20**	**0.50**	**0.53**	**0.50**	**0.50**	**0.14**	**0.10**	**0.08**	**0.08**	**0.07**
Phase I	0.40	0.60	0.60	0.58	0.58	0.20	0.55	0.52	0.50	0.50	0.22	0.12	0.10	0.10	0.09
Phase II	0.21	0.49	0.55	0.53	0.54	0.19	0.47	0.54	0.50	0.49	0.09	0.08	0.07	0.06	0.06
DK	**0.08**	**0.51**	**0.57**	**0.55**	**0.56**	**0.08**	**0.47**	**0.47**	**0.45**	**0.44**	**0.06**	**0.10**	**0.08**	**0.08**	**0.08**
Phase I	0.09	0.62	0.70	0.67	0.67	0.09	0.55	0.51	0.50	0.49	0.06	0.15	0.11	0.11	0.11
Phase II	0.08	0.44	0.49	0.48	0.49	0.08	0.42	0.44	0.42	0.41	0.06	0.08	0.07	0.06	0.06
EE	**0.01**	**0.03**	**0.07**	**0.07**	**0.07**	**0.02**	**0.05**	**0.10**	**0.11**	**0.12**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
Phase I	0.02	0.01	0.05	0.05	0.05	0.03	0.02	0.12	0.13	0.13	0.02	0.00	0.01	0.01	0.01
Phase II	0.01	0.05	0.08	0.08	0.09	0.01	0.07	0.09	0.10	0.11	0.01	0.01	0.01	0.01	0.01
ES	**0.12**	**0.30**	**0.33**	**0.34**	**0.34**	**0.12**	**0.25**	**0.32**	**0.32**	**0.31**	**0.07**	**0.06**	**0.05**	**0.05**	**0.05**
Phase I	0.07	0.28	0.30	0.31	0.30	0.08	0.17	0.27	0.27	0.27	0.04	0.07	0.05	0.06	0.06
Phase II	0.16	0.32	0.35	0.36	0.37	0.14	0.30	0.35	0.34	0.34	0.09	0.06	0.05	0.05	0.04
FI	**0.09**	**0.16**	**0.30**	**0.30**	**0.31**	**0.08**	**0.23**	**0.29**	**0.27**	**0.27**	**0.06**	**0.04**	**0.05**	**0.04**	**0.04**
Phase I	0.11	0.19	0.35	0.34	0.34	0.11	0.32	0.36	0.34	0.34	0.07	0.05	0.06	0.05	0.05
Phase II	0.07	0.15	0.27	0.27	0.29	0.06	0.17	0.24	0.23	0.23	0.06	0.03	0.04	0.04	0.04
FR	**0.16**	**0.56**	**0.68**	**0.65**	**0.65**	**0.21**	**0.49**	**0.63**	**0.60**	**0.60**	**0.06**	**0.10**	**0.09**	**0.09**	**0.08**
Phase I	0.14	0.53	0.64	0.62	0.62	0.25	0.42	0.59	0.57	0.57	0.04	0.11	0.09	0.09	0.09
Phase II	0.17	0.58	0.71	0.67	0.68	0.18	0.54	0.65	0.63	0.61	0.08	0.10	0.09	0.08	0.08
GB	**0.17**	**0.64**	**0.74**	**0.72**	**0.73**	**0.17**	**0.56**	**0.61**	**0.60**	**0.61**	**0.06**	**0.12**	**0.11**	**0.10**	**0.10**
Phase I	0.23	0.58	0.70	0.69	0.68	0.18	0.48	0.50	0.49	0.48	0.10	0.12	0.11	0.11	0.11
Phase II	0.13	0.67	0.76	0.75	0.76	0.16	0.61	0.68	0.67	0.69	0.04	0.12	0.10	0.09	0.09
GR	**0.02**	**0.04**	**0.07**	**0.06**	**0.07**	**0.01**	**0.06**	**0.11**	**0.10**	**0.11**	**0.02**	**0.01**	**0.01**	**0.01**	**0.02**
Phase I	0.01	0.00	0.02	0.02	0.04	0.00	0.00	0.02	0.02	0.04	0.00	0.00	0.00	0.00	0.02
Phase II	0.02	0.06	0.10	0.09	0.09	0.02	0.10	0.16	0.15	0.15	0.02	0.01	0.01	0.01	0.02
HU	**0.05**	**0.03**	**0.12**	**0.11**	**0.11**	**0.05**	**0.04**	**0.15**	**0.15**	**0.16**	**0.05**	**0.01**	**0.02**	**0.02**	**0.02**
Phase I	0.06	0.00	0.08	0.07	0.07	0.06	0.01	0.14	0.14	0.14	0.06	0.00	0.01	0.01	0.01
Phase II	0.05	0.05	0.14	0.14	0.14	0.05	0.06	0.16	0.16	0.17	0.05	0.01	0.03	0.02	0.02

Table A.2 *(continued)*

	In-Degree Centrality					Out-Degree Centrality					PageRank				
	Oha	**Pha**	**Oha & Pha**	**Oha & Pha & Ha**	**All**	**Oha**	**Pha**	**Oha & Pha**	**Oha & Pha & Ha**	**All**	**Oha**	**Pha**	**Oha & Pha**	**Oha & Pha & Ha**	**All**
IE	**0.02**	**0.06**	**0.15**	**0.16**	**0.17**	**0.03**	**0.06**	**0.11**	**0.13**	**0.14**	**0.01**	**0.02**	**0.03**	**0.03**	**0.03**
Phase I	0.02	0.02	0.11	0.13	0.12	0.03	0.03	0.07	0.10	0.10	0.01	0.01	0.03	0.04	0.04
Phase II	0.01	0.09	0.18	0.18	0.21	0.02	0.08	0.13	0.15	0.17	0.01	0.02	0.03	0.03	0.03
IT	**0.08**	**0.21**	**0.28**	**0.27**	**0.29**	**0.06**	**0.19**	**0.24**	**0.23**	**0.24**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**
Phase I	0.09	0.09	0.19	0.19	0.18	0.06	0.08	0.15	0.15	0.14	0.07	0.03	0.03	0.03	0.03
Phase II	0.08	0.28	0.34	0.32	0.36	0.05	0.25	0.30	0.28	0.30	0.03	0.06	0.05	0.04	0.04
LI	**0.00**	**0.11**	**0.10**	**0.10**	**0.10**	**0.00**	**0.11**	**0.10**	**0.10**	**0.10**	**0.00**	**0.02**	**0.01**	**0.02**	**0.01**
Phase II	0.00	0.11	0.10	0.10	0.10	0.00	0.11	0.10	0.10	0.10	0.00	0.02	0.01	0.02	0.01
LT	**0.01**	**0.02**	**0.07**	**0.07**	**0.07**	**0.01**	**0.05**	**0.13**	**0.13**	**0.13**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
Phase I	0.01	0.02	0.08	0.08	0.08	0.02	0.05	0.13	0.13	0.13	0.01	0.01	0.01	0.01	0.01
Phase II	0.01	0.01	0.06	0.06	0.07	0.01	0.06	0.12	0.13	0.13	0.01	0.01	0.01	0.01	0.01
LU	**0.00**	**0.03**	**0.03**	**0.05**	**0.06**	**0.01**	**0.01**	**0.03**	**0.04**	**0.04**	**0.00**	**0.01**	**0.01**	**0.02**	**0.02**
Phase I	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.02	0.02	0.00	0.00	0.00	0.01	0.01
Phase II	0.01	0.05	0.05	0.08	0.09	0.01	0.02	0.04	0.05	0.05	0.00	0.01	0.01	0.02	0.02
LV	**0.01**	**0.01**	**0.05**	**0.05**	**0.06**	**0.01**	**0.01**	**0.10**	**0.10**	**0.11**	**0.01**	**0.00**	**0.01**	**0.01**	**0.01**
Phase I	0.02	0.00	0.04	0.05	0.05	0.01	0.01	0.12	0.12	0.12	0.02	0.00	0.01	0.02	0.01
Phase II	0.01	0.02	0.06	0.05	0.06	0.01	0.02	0.09	0.09	0.09	0.01	0.00	0.01	0.01	0.01
MT	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**
Phase I	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.01
Phase II	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
NL	**0.10**	**0.51**	**0.61**	**0.61**	**0.63**	**0.11**	**0.50**	**0.53**	**0.52**	**0.53**	**0.04**	**0.09**	**0.09**	**0.08**	**0.08**
Phase I	0.13	0.54	0.63	0.62	0.61	0.17	0.53	0.53	0.51	0.51	0.06	0.11	0.10	0.09	0.09
Phase II	0.09	0.48	0.60	0.60	0.63	0.08	0.49	0.53	0.52	0.54	0.03	0.08	0.08	0.07	0.07
NO	**0.03**	**0.06**	**0.10**	**0.11**	**0.14**	**0.03**	**0.08**	**0.11**	**0.10**	**0.12**	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**
Phase II	0.03	0.06	0.10	0.11	0.14	0.03	0.08	0.11	0.10	0.12	0.01	0.01	0.02	0.02	0.02
Others	**0.00**	**0.00**	**0.00**	**0.14**	**0.13**	**0.00**	**0.00**	**0.00**	**0.11**	**0.31**	**0.00**	**0.00**	**0.00**	**0.02**	**0.02**
Phase II	0.00	0.00	0.00	0.14	0.13	0.00	0.00	0.00	0.11	0.31	0.00	0.00	0.00	0.02	0.02
PL	**0.06**	**0.19**	**0.24**	**0.23**	**0.22**	**0.06**	**0.23**	**0.27**	**0.26**	**0.26**	**0.04**	**0.04**	**0.03**	**0.03**	**0.03**
Phase I	0.04	0.06	0.10	0.10	0.10	0.05	0.13	0.18	0.18	0.18	0.02	0.02	0.02	0.02	0.01
Phase II	0.07	0.27	0.32	0.31	0.30	0.07	0.29	0.32	0.32	0.31	0.06	0.05	0.05	0.04	0.04
PT	**0.06**	**0.09**	**0.15**	**0.14**	**0.14**	**0.07**	**0.09**	**0.19**	**0.18**	**0.17**	**0.04**	**0.02**	**0.03**	**0.02**	**0.02**
Phase I	0.04	0.03	0.10	0.10	0.10	0.05	0.04	0.16	0.16	0.16	0.03	0.01	0.02	0.02	0.02
Phase II	0.07	0.13	0.18	0.17	0.17	0.08	0.12	0.20	0.19	0.18	0.05	0.03	0.03	0.03	0.03
RO	**0.00**	**0.08**	**0.12**	**0.12**	**0.14**	**0.02**	**0.11**	**0.18**	**0.16**	**0.19**	**0.00**	**0.01**	**0.02**	**0.01**	**0.02**
Phase II	0.00	0.08	0.12	0.12	0.14	0.02	0.11	0.18	0.16	0.19	0.00	0.01	0.02	0.01	0.02
SE	**0.06**	**0.15**	**0.21**	**0.22**	**0.24**	**0.09**	**0.15**	**0.23**	**0.24**	**0.25**	**0.04**	**0.04**	**0.03**	**0.03**	**0.04**
Phase I	0.09	0.15	0.20	0.20	0.20	0.13	0.18	0.30	0.29	0.29	0.07	0.04	0.04	0.04	0.04
Phase II	0.05	0.15	0.22	0.23	0.27	0.06	0.14	0.19	0.20	0.23	0.02	0.03	0.03	0.03	0.03
SI	**0.01**	**0.05**	**0.07**	**0.08**	**0.09**	**0.01**	**0.04**	**0.07**	**0.07**	**0.08**	**0.01**	**0.01**	**0.02**	**0.03**	**0.03**
Phase I	0.01	0.02	0.06	0.07	0.07	0.01	0.01	0.03	0.03	0.03	0.01	0.01	0.04	0.05	0.05
Phase II	0.01	0.07	0.08	0.08	0.11	0.02	0.06	0.10	0.09	0.11	0.01	0.01	0.01	0.01	0.02
SK	**0.04**	**0.11**	**0.17**	**0.16**	**0.16**	**0.05**	**0.17**	**0.27**	**0.25**	**0.24**	**0.02**	**0.02**	**0.03**	**0.02**	**0.02**
Phase I	0.02	0.04	0.10	0.10	0.10	0.03	0.11	0.21	0.21	0.21	0.01	0.01	0.02	0.02	0.02
Phase II	0.05	0.16	0.22	0.20	0.20	0.07	0.20	0.31	0.28	0.27	0.03	0.03	0.03	0.03	0.03
UA	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.04**	**0.04**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Phase II	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.00	0.00	0.00	0.00	0.00

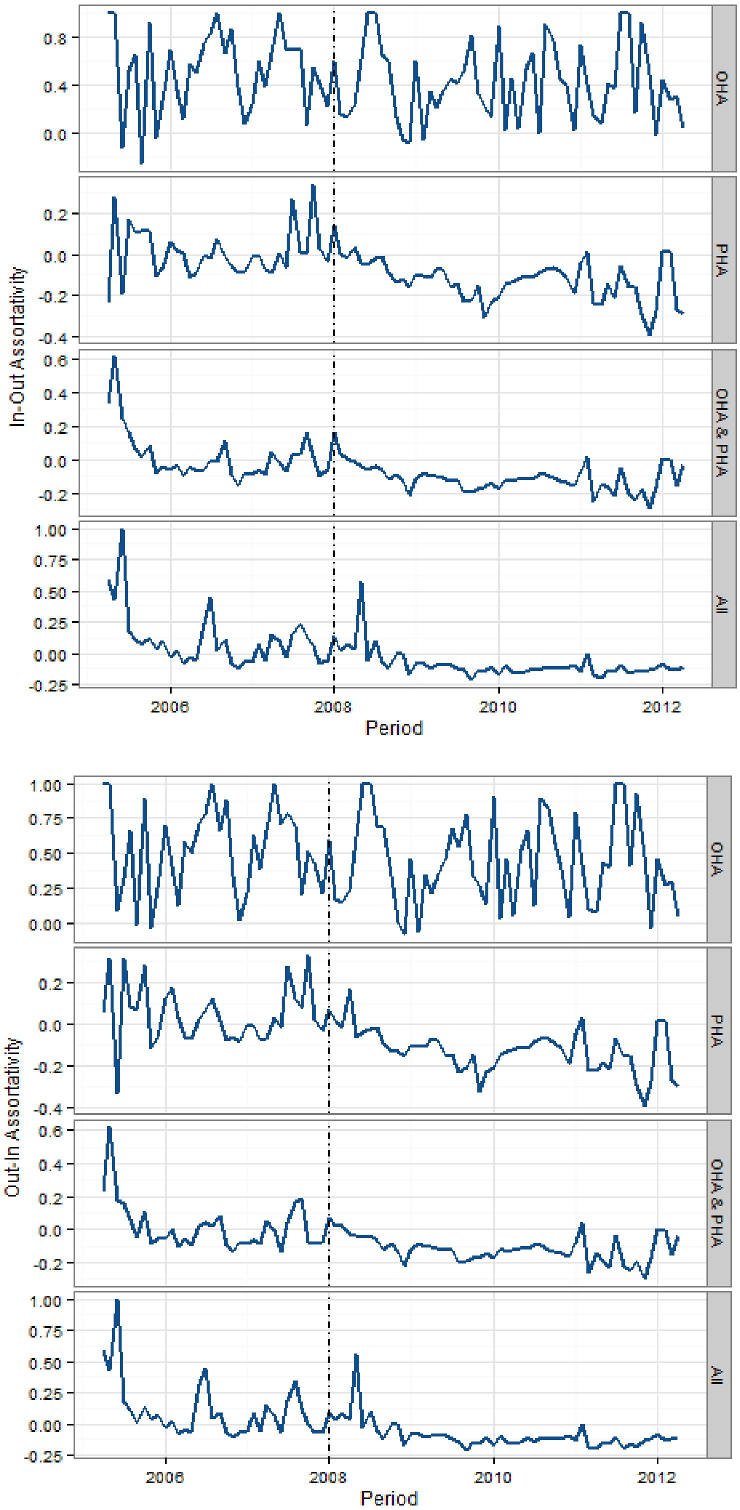
A.3 PageRank under scenario *b*

Figure 5: PageRanks for different Account Types and Transaction Codes (Scenario b)



A.4 Assortativity coefficients under scenario *a*

Figure 6: Assortativity Coefficients (IN-OUT and OUT-IN) for OHAs, PHAs, OHAs & PHAs and All types of account under scenario *a*



A.5 Assortativity coefficients under scenario *b*

Figure 7: Assortativity Coefficients (IN-IN and OUT-OUT) for OHAs, PHAs, OHAs & PHAs and All types of account under scenario *b*

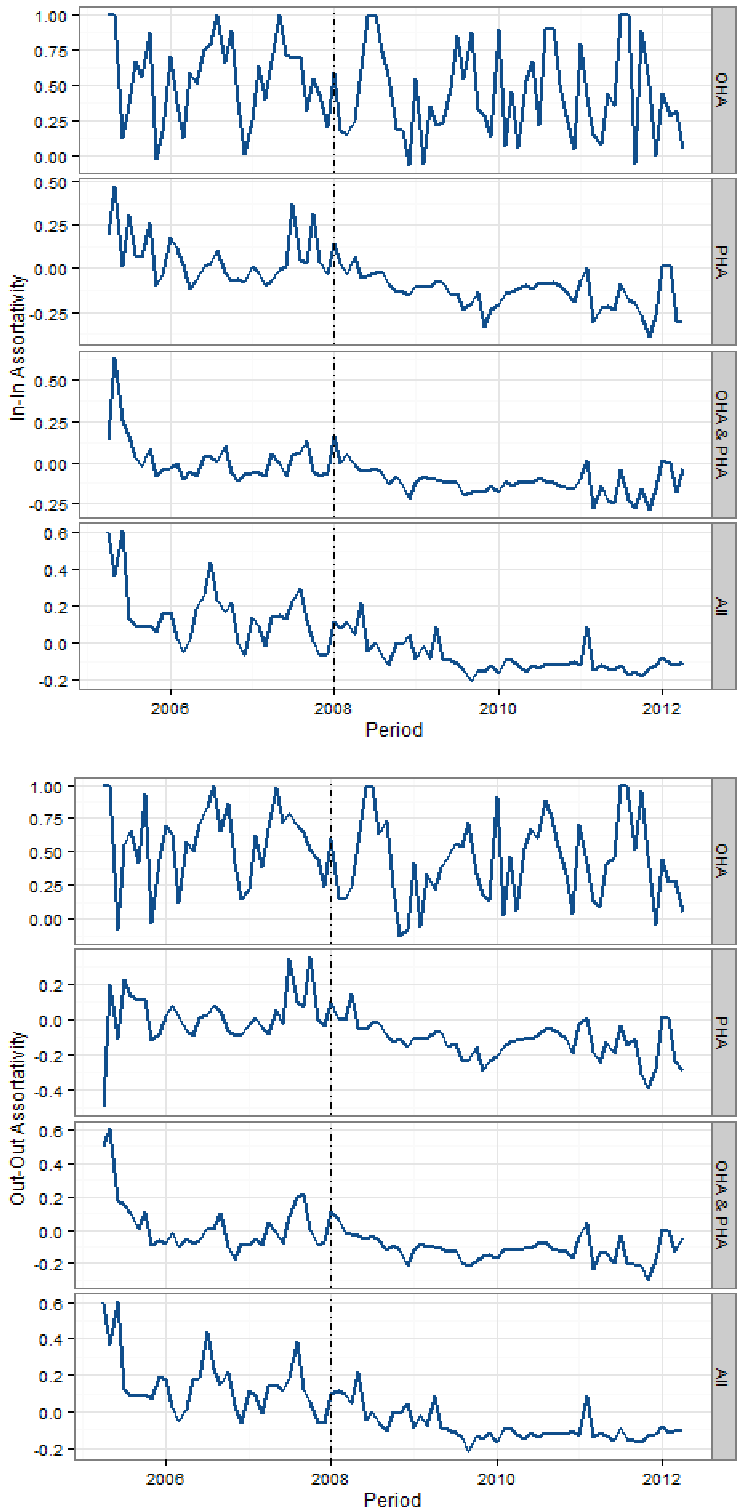
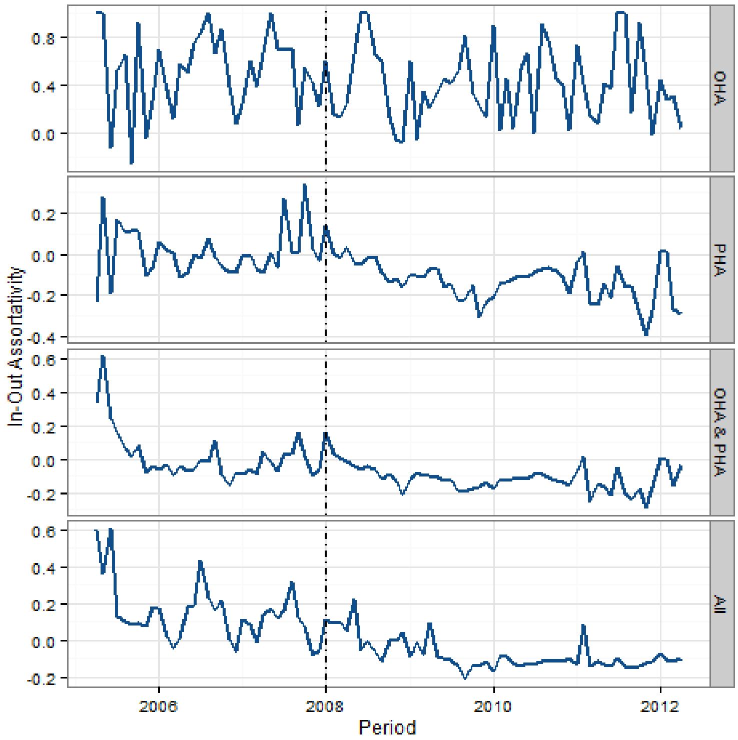
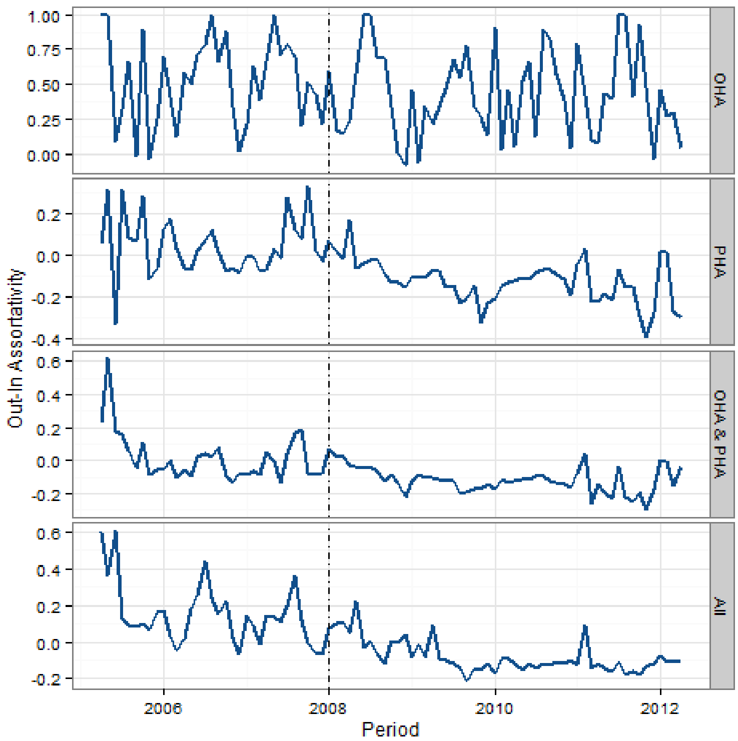


Figure 8: Assortativity Coefficients (IN-OUT and OUT-IN) for OHAs, PHAs, OHAs & PHAs and All types of account under scenario *b*





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