Understanding the EU ETS Market Structure Using Transactions of Core Participants

DIMOS S.[1],* EVANGELATOU E.[2], FOTAKIS D.[3], MANTIS A[4]. and MATHIOUDAKI A.[5]

[1, 2, 3, 4, 5] **School of Electrical and Computer Engineering, National Technical University of Athens, Iroon Polytechniou 9, 15780 Athens**

*corresponding author **e-mail: sdimos@corelab.ntua.gr**

Abstract European Union Emission Trading System (EU ETS) is a key instrument of EU's climate policy and the largest international cap-and-trade system. Every allowance transaction is recorded in an electronic registry, called European Union Transaction Log (EUTL). Utilizing the vast amount of EUTL data, we exploit the EU ETS transaction network as a means for understanding in depth the allowance market structure. We observe that the network follows the core-periphery structure and identify a small subset of core transactors. We provide strong evidence that despite its small size, the part of the network built around core transactors captures all the key properties of the entire EU ETS transactions network. Moreover, due to high and more regular trading, the transactions of the core members lack the "noisy" behaviour typically appearing in the periphery. Through extensive evaluation, we demonstrate that the core transactions can provide better results in explaining and forecasting the allowance price. Our work provides a compact and useful tool which can be used not only towards understanding a large and complex allowance market, but also towards evaluating one of the most prominent environmental policy instruments, the EU ETS.

Keywords: Emission Trading System, cap-and-trade, ETS transaction network, core-periphery structure, forecasting

1. Introduction

The European Union Emission Trading System (EU ETS), is Europe's main climate and energy policy. Through the institutional framework of the EU ETS firms can buy or sell allowances (EUA) in order to cover for their annual emissions and hence the allowance price is determined by the created allowance market. Over the years it has attracted the global scientific interest due to its large size and its international market (see e.g. [1], [2], [3]).

An important aspect of the EU ETS is the European Union Transaction Log (EUTL). EUTL is the electronic registry where every allowance transaction made within the EU ETS is recorded. This rich source of data can be used to reproduce the transaction network allowing for a better understanding of the market structure and its characteristics.

Previous studies on the characteristics of the transaction network [4], [5] indicate that the EU ETS market exhibits a core-periphery structure. Generally, it has been observed that many trading networks exhibit such a core-periphery structure (e.g. [6], [7], [8]). Hence, in our analysis, we follow the growing volume of the literature that investigates the EU ETS market structure using a network-based approach. Aiming for a better understanding of how the ETS market operates, we are interested in finding a small set of core participants and exploring its characteristics. To that end, we refine the network structure by considering a subset of participants that "covers" most of the network, i.e. an approximate dominating set. We found such a subset which is tiny in size, but it transacts with the rest of the network and it is responsible for the exchange of the main trading volume. Furthermore, we show that on average the annual verified emissions of the members of this set are higher than that of any other participant in the EU ETS.

We claim that the aforementioned core encompasses all the necessary and noise free information. In other words, we expect that the same qualitative conclusions can be drawn either by focusing on the entire network, or only on the core transactors. Therefore to further enhance the significance of our findings, we perform a Vector Autoregression analysis to forecast the allowance price, using the actual trading volumes of this set, along with known price determinants (see e.g. [9] [10] [11] [12]). Finally, we show that we can obtain better forecast results by exploiting the trading volumes of the core participants.

2. Designate the core transactors

In this section, we present the procedure to identify the core of the EU ETS transaction network. Naturally, exchanging EUAs can be modeled as a network $G(V, E)$. We therefore consider as the set of nodes V the firms, i.e. account holders. If there is at least one transaction between two nodes v and w, we add an edge $\{v, w\} \in E$.

We consider monthly networks constructed by the allowance exchange date from the EUTL [13]. We classify the participants as (a) regulated, (b) financial, and (c)

governmental, according to their main functionality within the EU ETS following the methodology in [14]. In a nutshell, regulated entities are polluters, governmental are European bureaus, and financial entities are banks, brokers and intermediaries, which are supposed to ease the transactions.

Our main goal is to find a small subset of nodes, i.e. firms that transact with the rest of the network. To do so, we define the (node) coverage of a subset D of V as the portion of nodes which are connected to or "covered" by D. A *dominating set* for a graph (V, E) is a subset D of V such that every vertex not in D is adjacent to at least one member of D. Finding the minimum dominating set of a given graph is an NP-hard problem [15], which means that it is unlikely to exist an efficient algorithm to find it. So, we follow a heuristic approach in order to find almost dominating sets with few nodes. For each monthly network we follow the process:

1. exclude all nodes with at most one neighbour.
2. order the remaining nodes by their degree (number of neighbors) in decreasing order.

for each node of the aforementioned ordered list

3. choose that node v, if v has at least one neighbour not already chosen.

Table 1: Statistics for the number of nodes, |V|, the number of the members of the Almost Dominating sets, |D| and the for the monthly networks.

	min	median	max	mean	std
$\lvert V\rvert$	242	966	6,993	1,865	1,810.46
$\lvert\mathcal{D}\rvert$	19	67	160	71	30.84
$\frac{\lvert V\rvert}{\lvert\mathcal{D}\rvert}$	0.32%	6.34%	12.57%	6.15%	2.99%

The majority of the participants do not transact every month, so the size of the networks varies significantly, as indicated by Table 1. To circumvent the dependence of the network (and of the approximate dominating set) on time, we are interested in identifying a set of participants that does not change over time and covers most of the nodes in every monthly network. We refer to that set as the **core of the EU ETS**. Towards computing the core, we take the union of the monthly almost dominating sets, computed according to the algorithm above. Then for each node, v, we calculate the frequency, f_v, that v appears in the monthly almost dominating sets and sort the nodes in non-increasing order of their frequencies. Then, let G be a monthly network. We repeatedly consider nodes v in decreasing order according to f_v; v is chosen to be a member of the **core** until 97% of the nodes of G is covered. We repeat this process for each monthly network. So, by construction the members of the **core** cover at least 97% of every monthly network. Figure 1 shows that the majority of the core is financial entities.

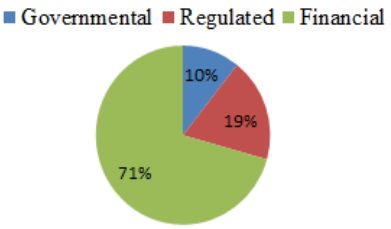

Figure 1: Composition of the core by category

3. Characteristics and assessment of the Core

Generalizing the previous approach, to assess the importance of the core, we next consider the actual trading and emission volumes of its members. Recall that the core set is generated based on the number of the transactions made by its participants, completely ignoring the transaction volume. To that end, we partition firms into five categories, based on either their trading volumes or their emission volumes. These categories are (a) tiny, (b) small, (c) average, (d) big and (e) colossal.

Given the quantity of interest (i.e., trading volumes or verified emissions), we compute for each participant, i, the natural logarithm of the average annual quantity, let say $\ln(E[q_i])$. Let $M = max_i\{\ln(E[q_i])\}$. We divide the interval [0, M] in five equal subintervals. A firm, i, is designated as tiny, small, and so on according to which subinterval quantity $\ln(E[q_i])$ falls.

3.1. Size of the Core

In Tables 2, 3 one can see the number of participants in the core set along with its size in terms of their trading volumes and of their emission volumes respectively. Both tables indicate the tiny size of the core!

Table 2: Core vs periphery in terms of trading volumes.

Trade Volume	**core**	**periphery**
tiny	0	4,660
small	0	7,536
average	57	2,664
big	72	781
colossal	106	228
sum	**235**	**15,869**

Table 3: Core vs periphery in terms of verified emissions.

Emission Volume	**core**	**periphery**
tiny	3	1,777
small	3	1,720
average	7	5,740
big	18	1,857
colossal	13	191
sum	**44**	**11,285**

More than 15,000 account holders (firms or bureaus) are registered in the EUTL. As seen in Table 1, the monthly networks can reach up to 6,993 nodes. However, the core set consists of only 235 members.

3.2. The Core includes large transactors

Figure 2 shows the distribution of the size of the regulated entities in terms of trading volume. We highlight that we consider transaction types only related to pure trade/exchange, excluding any type related to free allocation or surrendering of allowances. Regarding all the account holders (blue line) most of the participants are classified as "tiny" or "small", as they fall into the first two intervals defined by the green dashed lines. It is worth mentioning that around 30% of the registered entities have negligible transacting volumes. In contrast, regarding the members of the core (red line), the majority is classified as "big" or "colossal" as the two peaks are pictured between the last two intervals. This highlights the significance of the core, as its members not only make the most transactions, but also they exchange far larger trading volumes.

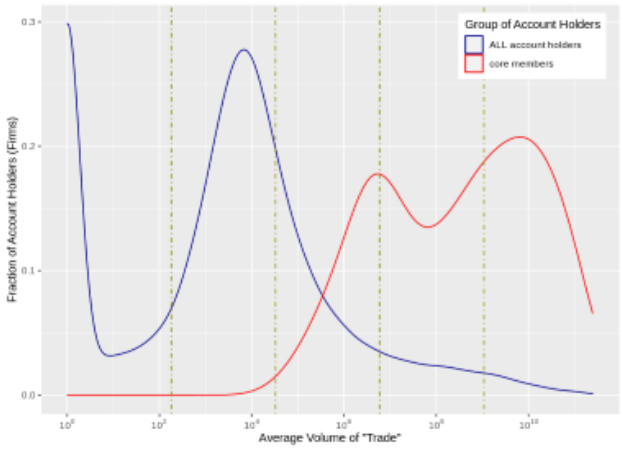

Figure 2: Distribution of Account Holders in terms of trading Volumes. Transactions related to free allocation and surrendering for compliance are not taken into account.

Moving forward to Figure 3 and to the distribution of the size of the regulated firms in terms of emission volume, one can see (blue line) that the majority of the account holders is classified as "average" as they are clearly located inside the middle interval. However, by observing the core (red line) most of its members are "big" and "colossal", which in turn lead us to the conclusion that the core mostly consists of firms with large amounts of annual verified emissions.

To further analyze the significance in terms of the emission volumes, one can observe the Figure 4. It is clear that on average the annual verified emissions of a firm/member of the core (purple line) are higher than the annual verified emissions of a firm outside the core (blue line). The same is also true compared with the annual verified emissions of any firm in the entire network (red line) on average.

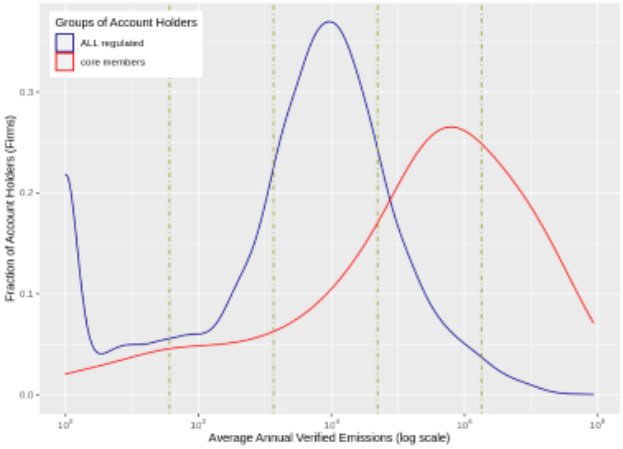

Figure 3: Distribution of Account Holder size in terms of verified emissions.

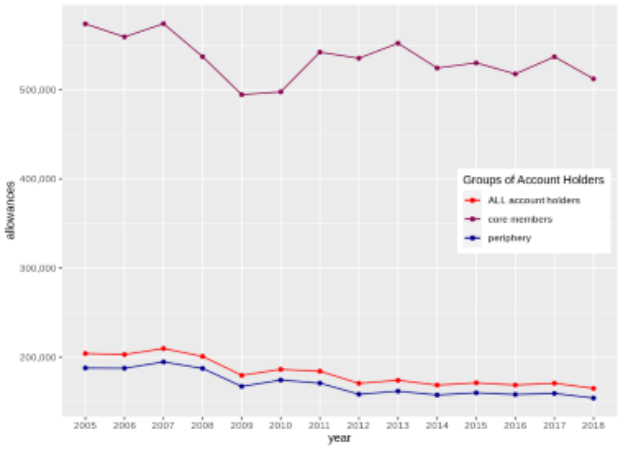

Figure 4: Average Verified Emissions from installations of Firms belonging to the core vs those belonging to the periphery

3.3 Core trading volumes as an EUA price determinant

Allowance price is often viewed as a performance indicator of the EU ETS [1]. In an attempt to further highlight the significance of the core, we use the trading volumes of the core participants along with known price determinants (see [9] - [12]) and perform a Vector Autoregression analysis to forecast the EUA price.

As a first step, we consider aggregating trading volumes concerning the financial and regulated firms of the entire network and the corresponding amounts concerning both categories of the core. Then, we follow the usual procedure of the analysis and perform all the necessary steps, i.e. testing for stationarity, lag-length selection, residual diagnostics, assessing the stability of the selection models, and finally assessing the forecast accuracy. For an in-depth analysis of the data used, the procedure and the detailed results, one can see [16].

The selected VAR model consists of a mixture of known price determinants i.e. Natural Gas prices, Oil prices and Coal prices and the total trading volumes of the financial participants and the regulated participants. As expected, the model has a better forecast performance when the trading volumes are restricted to the core participants (see

Table 4). Both the Mean Squared Error (MSE) and Mean Absolute Error (MAE) are slightly improved when the model uses the trading volumes of the core.

Table 4: Forecast errors for the selected VAR model.

	MAE	MSE
core	0.245	0.096
entire network	0.251	0.097

4. Conclusions

In this work we present a network-based approach aiming for a better understanding of the EU ETS market structure. Since the EU ETS exhibits a core - periphery structure, we focus on finding this subset of participants which constitute the core and explore their characteristics. We show that despite its small size, the core consists of members that exchange the most of the trading volumes. Moreover, they have higher on average annual verified emissions compared to the rest of the regulated entities. Finally, to further demonstrate the usefulness and the significance of the core, we use the trading volumes of the core nodes and perform Vector Autoregression analysis, aiming to forecast the EUA price. As expected, the forecast models that include the trading volumes of the core perform better than the models that include the trading volumes of the entire network. As future work, it would be interesting to calculate the core by exploiting the directed and weighted version of the network. Furthermore, it would be of great interest to investigate potential correlations between each firm's position in the EU ETS transaction network and important features, such as its stock price or its stock market value. A similar relationship has been uncovered in the world trade network, where the countries that belong to core tend to have greater GDP and Capital Stock [17].

References

[1] Denny Ellerman, Claudio Marcantonini, and Aleksandar Zaklan, "The European Union Emissions Trading System: Ten Years and Counting.," *Review of Environmental Economics and Policy*, vol. 10, pp. 89-107, 2015.

[2] Beat Hintermann, Sonja Peterson, and Wilfried Rickels, "Price and Market Behavior in Phase II of the EU ETS: A Review of the Literature.," *Review of Environmental Economics and Policy*, vol. 10, pp. 108–128, 2015.

[3] Ralf Martin, Mirabelle Muuls, and Ulrich Wagner, "The Impact of the European Union Emissions Trading Scheme on Regulated Firms: What Is the Evidence after Ten Years?," *Review of Environmental Economics and Policy*, vol. 10, pp. 129–148, 2015.

[4] Andreas Karpf, Antoine Mandel, and Stefano Battiston, "Price and network dynamics in the European carbon market," *Journal of Economic Behavior & Organization*, no. 153, pp. 103 – 122, 2018.

[5] Regina A. Betz and Tobias S. Schmidt, "Transfer patterns in Phase I of the EU Emissions Trading System: a first reality check based on cluste analysis.," *Climate Policy*, no. 16, pp. 474-495, 2016.

[6] Boss Michael, Helmut Elsinger, Martin Summer, and Stefan Thurner, "Network topology of the interbank market.," *Quantitative finance*, no. 4, pp. 677–684, 2004.

[7] Van Lelyveld Iman et al., "Finding the core: Network structure in interbank markets.," *Journal of Banking & Finance*, no. 49, pp. 27-40, 2014.

[8] Fricke Daniel and Thomas Lux, "Core-periphery structure in the overnight money market: evidence from the e-mid trading platform.," *Computational Economics*, no. 45, pp. 359–395, 2015.

[9] Christiansen Atle, Arvanitakis Andreas, Tangen Kristian, and Hasselknippe Henrik, "Price determinants in the EU emissions trading scheme," *Climate Policy*, no. 5, pp. 15–30, 2005.

[10] Frank Convery and Luke Redmond, "Market and Price Developments in the European Union Emissions Trading Scheme.," *Review of Environmental Economics and Policy*, no. 1, pp. 88–111, 2007.

[11] Emilie Alberola, Julien Chevallier, and Benoit Cheze, "Price drivers and structural breaks in European carbon prices 2005-2007.," *Energy Policy*, no. 36, pp. 787-797, 2008.

[12] Maria Mansanet-Bataller, Angel Pardo, and Enric Valor, "CO2 Prices, Energy and Weather.," *The* , no. 28, pp. 73–92, 2007.

[13] European Union Transaction Log. [Online]. https://ec.europa.eu/clima/ets/

[14] S. Dimos, E. Evangelatou, D. Fotakis, A. Mantis, and A. Mathioudaki, "On the impacts of allowance banking and the financial sector on the EU Emissions Trading System," *Euro-Mediterranean Journal for Environmental Integration*, no. 5, pp. 1-25, 2020.

[15] Michael R. Garey and David S. Johnson, *Computers and Intractability: A Guide to the Theory of NP-Completeness*. New York, USA: W. H. Freeman & Co., 1979.

[16] Sotirios Dimos, Eleni Evangelatou, Dimitris Fotakis, Andreas Mantis, and Angeliki Mathioudaki, "Forecasting EU Allowance Price Using Transactions of Central Entities," *Advances in Ecological and Environmental Research*, pp. 187 – 209.

[17] Anida Sarajlić, Noël Malod-Dognin, Ömer Nebil Yaveroğlu, and Nataša Pržulj, "Graphlet-based characterization of directed networks," *Scientific reports*, no. 6, pp. 1-14, 2016.