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On the topological structure of multinationals network[☆]

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HIGHLIGHTS

- The underlying countries network of French multinationals' foreign affiliates is revealed and studied.
- Vertex (host countries) and dyad (investing firms) specific metrics are in line with previous findings on foreign direct investments.
- Network-wide metrics bring an original insight to the topic.
- The change of the network structure over 7 years shows a decentralization trend.
- Firm heterogeneity seems to matter in network building, with least productive firms following more common internationalization strategies.

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ABSTRACT

This paper uses a weighted network analysis to examine the structure of multinationals' implantation countries network. Based on French firm-level dataset of multinational enterprises (MNEs) the network analysis provides information on each country position in the network and in internationalization strategies of French MNEs through connectivity preferences among the nodes. The paper also details network-wide features and their recent evolution toward a more decentralized structure. While much has been said on international trade network, this paper shows that multinational firms' studies would also benefit from network analysis, notably by investigating the sensitivity of the network construction to firm heterogeneity.

1. Introduction

Since the early 2000s an increasing number of papers have focused on the empirical examination of economic networks structure. Among them international trade, through the World Trade Web (WTW) analysis, has been one of the first – and probably also one of the most – economic field studied through a network approach. Pioneer works study topological properties of the WTW [1–7]. Then more precise issues were addressed through the network analysis, as the evolution of the WTW structure over time [8], or the sectoral differences in the trade network [9,10]. However, the current globalization is rather driven by Multinational Enterprises (MNEs), Foreign Direct Investments (FDIs) and intra-firm trade than by arm's length trade [11,12]. Surprisingly, only a few works explored the structure of FDI networks of multinational firms. Nonetheless, the high interdependences between related affiliates coordinated by common headquarters, which share capital, workers and technologies besides goods, calls for a network approach to better understand the geographical breakdown of their global structure.

Sgrignoli [13] compares the two network structures of countries bilateral trade flows (WTW) and bilateral Foreign Direct Investment (FDIN), and shows that both share a disassortative pattern and a similar (and very concentrated) strength

☆ The access to the data was carried through the CASD dedicated to researchers authorized by the French *Comité du secret statistique*.

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distribution. However, the bilateral network structure blurs the individual MNEs boundaries. Conversely, focusing on Italian firm FDI network, de Masi et al. [14] build a bipartite network of investing firms and host countries, and alternatively use projection on the "firm space" (resulting in a network of firms, linked according to the common number of countries they have invested in), and more rarely develop the projection on the "country space" (resulting in a network of countries, linked according to the number of firms that are jointly present in both countries), but do not give much information about the latter.

This paper has two premises: first, the recent increase in firm-level data availability, coupled improvement in computability of network analysis through statistical softwares.[1] Second, as noted above, the fact that the international trade networks are now commonly studied, whereas FDIs and more especially multinational firms networks are still to explore. Using firm-level data on French multinationals, this paper aims at revealing the topological structure of the underlying network of MNEs' implantation countries, and properly quantify this properties through vertex-specific, dyad-specific and network-wide measures. Similarly to world trade network, the analysis shows a high centralization degree and a disassortative pattern of the network structure. However, while Fagiolo et al. [8] note that the WTW structure did not change much since the 1980*s*, this paper shows that the MNEs network did evolve more recently toward a decentralized structure. Moreover, further results tend to indicate that firm heterogeneity plays a role in the FDI network building.

The paper is constructed as follows: in Section 2, I detail the network building methodology. Then Section 3 reveals the network's topological structure, and how it evolved over time. Section 4 Insists on the firms internationalization path, and the way the network expands. The following section presents two sub-networks according to firm heterogeneity. Finally, Section 6 concludes.

2. Network building

Based on French firm-level data of foreign affiliates' location, I built a weighted directed network (WDN) of multinational firms, where the nodes are the world's countries. Two countries are linked if they both host an affiliate of the same MNE. The direction of the arcs indicates the chronological sequence of the multinational expansion.[2] Then each arc is weighted corresponding to the number of firms using this country association, in that order, to highlight similar pattern of international expansions of French firms. The resulting network pattern is very close to the one built by de Masi et al. when detailing the projection of their bipartite graph in the subspace of countries (see figure 3, in Ref. [14]), except for the additional direction information.

The data on foreign French affiliates comes from LiFi, a yearly survey run by the French national statistic institute (*INSEE*). It lists the subsidiaries of French firms identified as "head of group". Hence, our network is not only made of directly controlled affiliates, but also of the entities they could themselves own, ensuring a proper vision of the actual network of French multinationals. Only majority-held subsidiaries were considered. Although LiFi design involves threshold values, they are quite low for multinational firms, hence the non-reported firms – if any – may not lead networks large enough to significantly change the identified pattern of MNEs network.[3] Self loops were not considered, ignoring multiple-plants in a given country as the final objective is to study the pattern of country pairing. Also, France is not included in the network as it is the headquarters country of all firm considered. The set of countries is henceforth made of all countries, excluded France and countries without any French affiliate because they are not part the multinationals' network. In 2011 (last year available), the French multinationals' affiliates network counts 167 countries, implying over 27,720 (directed) arcs possibilities, with 2,996 firms and 19,872 subsidiaries composing it.[4] Fig. 1 displays a preview of the network.

3. Topological structure of multinationals network

3.1. Overview

Before examining the connectivity pattern of the network, an overview details the principal destinations of French FDIs, where unsurprisingly the USA stand first with over 12% of French affiliates in our sample. Below, the United Kingdom, Germany and Spain have a similar share of around 6% of French foreign subsidiaries. Concerning the pairs of countries used together, the three main associations in 2011 are Germany–Spain (done by 11.3% of French MNEs in our sample), followed by Italy–Spain (11.0%) and Germany–United Kingdom (10.8%). French firms seem to associate similar and relatively close countries in their international development. Although the USA are the main destination, they do not appear in the main associations of countries. This refers to the connectivity profiles of the USA, which might differ from European countries' one. To further examine this topic, let us introduce some network metrics.

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1 I am especially grateful to Thomas Grund and its nwcommands package for Stata. I also have developed my own Stata packages to compute some additional network metrics (ANND, ANNS, strength centralization, disparity, and weighted clustering coefficient), available on Boston College SSC archive.

2 Let W be the directed weighted adjacency matrix, and X the undirected weighted matrix. We therefore have $W + W' = X$. The total link between the two countries i and j is the sum of links from i to j and from j to i.

3 Only firms that fulfill one of the four following criteria are surveyed in LiFi: The participation into other firms outpaces 1.2 million euros; the firms employs at least 500 employees; its turnover is superior to 60 million euros; the firm has been previously identified as "head of group".

4 As a consequence of the research question, French MNEs with only one foreign affiliates were not included in the designed network, because they do not associate any country pairs.

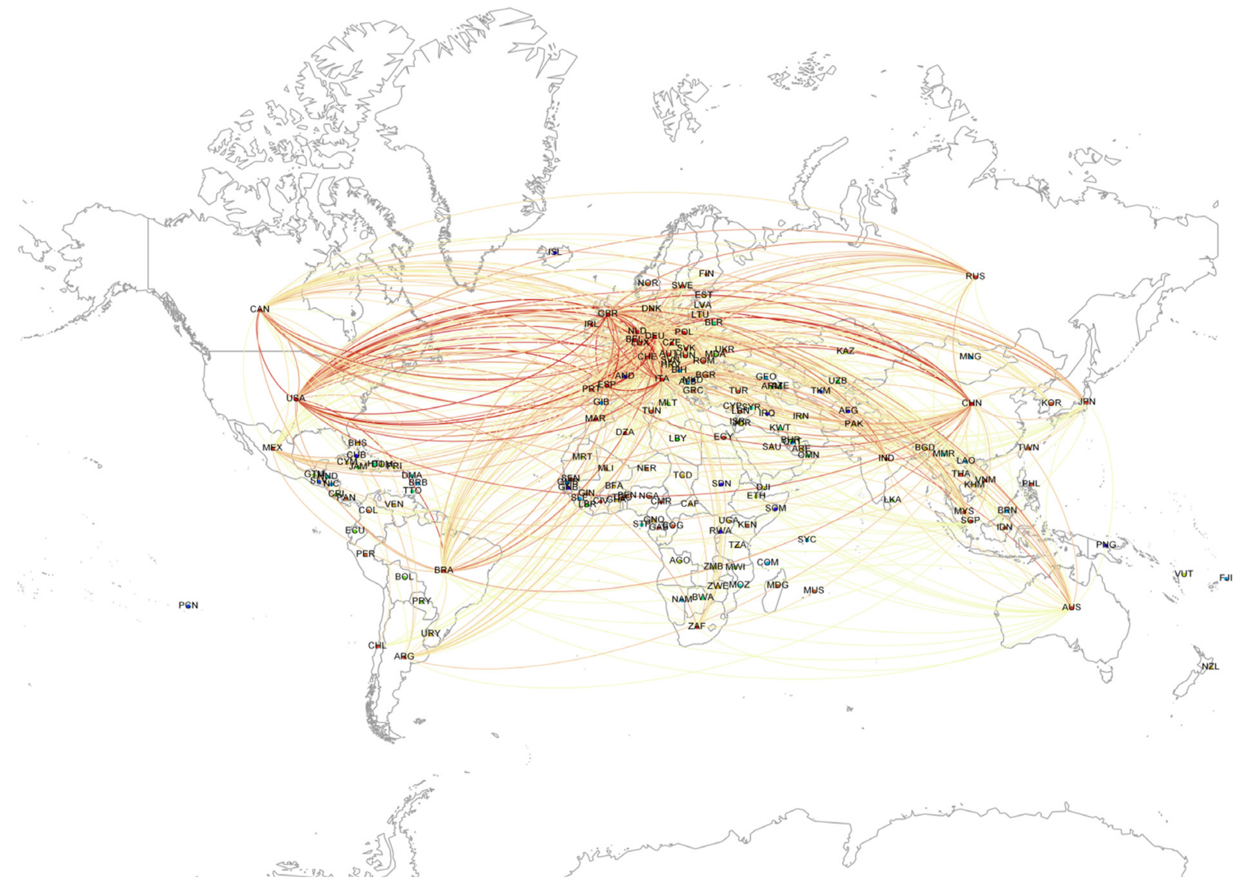

Fig. 1. Network of French MNEs in 2011 (main links). Note: Only the arcs used at least by 30 french MNE (i.e. with a weight above 30, namely 4.67% of the arcs) were kept to drop marginal linkages, and clean the picture. The arcs' color intensity is proportional to its weight (the number of firms using this association). Figure realized using Gephi.

3.2. Centrality measures

From the network binary adjacency matrix, one can draw two degree measures according to the chosen direction: the *inward degree* of node *i*, $k_i^i = \sum_i a_{ij}$ which sums the number of countries leading toward it; and the *outward degree* $k_i^o = \sum_j a_{ij}$, counting the number of nodes it gives access to. The figure (2, first row) presents the complementary cumulative distribution function of the nodes degree, defined as $P_c(k) \equiv \sum_{k*>k} P(k)$.

In this figure, the various countries flagged tend to show that a node's outward centrality is correlated to its economic size, whereas this relationship is blurred for the inward centrality. Also, very few nodes have a low inward degree, while the distribution of outward degree is more linearly distributed, but both are highly concentrated at the top of the distribution, with very few differences between the most central nodes. This is mainly due to the fact that the degree simply counts the number of neighbors, and consider equally all pairs of countries, whatever the number of firms using them. Referring to nodes *strength* allows to take frequencies into account, using the weighted adjacency matrix W which provides the eights associated to each link in every elements w_{ij} instead of a_{ij}, such that node *i inward strength* is defined as $s_n^i = \sum_i w_{ij}$ and *outward strength* as $s_n^o = \sum_j w_{ij}$ [15]. The strength distribution (Fig. 2, second row) is much more concentrated that the degree one, for both directions, although the outward strength concentration is higher as reveals the shape of the curve. Few countries are thus central in the network once considered the frequency of their use, and especially concerning the countries that give access to other ones.

Table 1 displays the centrality scores of most and least central nodes. While the outward centrality indexes display expected central countries, with the USA and France's neighboring countries, the inward degree index displays much surprising results, with developing countries in the top five positions. Those developing countries have the broader set of possible previous internationalization steps. The inward degree does not captures which countries are the most targeted by French MNEs, but the ones that could be invested after most countries. The inward strength index balance this conception by weighting by the actual number of firms using this association. The result is a mitigation of French neighboring countries, which are natural destination for French firms, to leading – and big – developing countries: China and India. The four

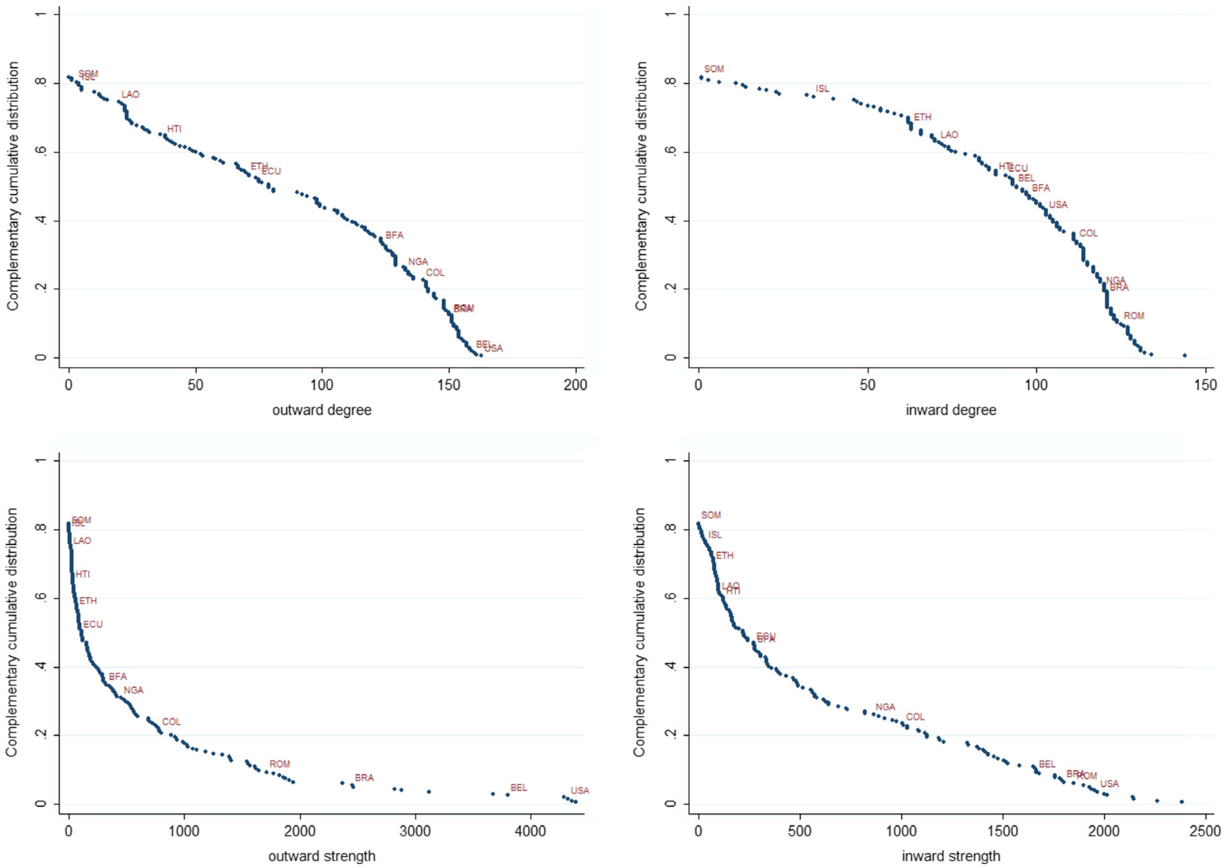

Fig. 2. Distribution of nodes Degree and Strength

centralization degree though are more alike when looking at the least central nodes, with small and poor countries displaying least central indexes. Comparing the average centrality of some countries groups shows that OECD members, neighboring countries, and the BRICS countries (Brazil, Russia, India, China and South Africa) display higher centrality than global average, with neighboring countries being the most central according to three of the four indexes. Neighboring countries are those that give French firms the broader further expansion possibilities (outward degree), and those from where French firms go the most elsewhere (outward strength).

Freeman developed a centralization index to synthesize the disparity among the nodes centrality indexes. The degree centralization [16] is computed as $C_D = \frac{\sum_{i=1}^{N}[k_{max}-k_i]}{(N-1)(N-2)}$. Following Freeman's principles, I develop a strength centralization index (see Appendix A for more details). Both indexes range in [0;1], the higher indicating a deeper centralized network. However, the two indexes cannot be compared one to another because of the exponential combination possibilities in the weighted version, that automatically decreases the strength centralization in empirical networks, but are useful to compare inward and outward centralization as in Table 2.

Both centralization indexes reveal a higher centralization in the outward centrality measures, rather that in inward ones. While this conclusion is obvious for the strength indexes from Fig. 2, the higher centralization of outward degree is due to the more numerous nodes at the tail of the distribution (i.e. with few outward degree) compared to the inward degree distribution. In this network, countries vary more according to the further destinations they offer, rather than the previous steps of internationalization that lead to them.

3.3. Two vertices correlation

While first-order centrality indexes describe the hierarchical structure of the network, highlighting central versus peripheral nodes, they tell very little about network construction. Second order metrics give information on the interaction between nodes, and linkages preferences, describing therefore the building network strategies. The first index computed is the average nearest neighbor degree (ANND), corresponding to the mean degree of direct neighbors. The correlation between a node's degree and the average degree of its neighbors reveals whether vertices of the network tend to link to similar

Table 1
Centrality measures.

Rank	Inward degree		Outward degree		Inward strength		Outward strength	
	country	(score)	country	(score)	country	(score)	country	(score)
1	UKR	(144)	USA	(163)	CHN	(2385)	GBR	4387
2	ARE	(134)	ESP	(161)	ESP	(2265)	ESP	4359
3	RUS	(132)	BEL	(160)	ITA	(2145)	USA	4324
4	DZA	(131)	DEU	(159)	IND	(2144)	DEU	4288
5	ZAF	(131)	GBR	(158)	DEU	(2018)	BEL	3805
...	...	...	...	...	...	...	...	...
163	AFG	(11)	ISL	(4)	AFG	(11)	ISL	(4)
164	SDN	(6)	SOM	(73)	SDN	(6)	SOM	(3)
165	CUB	(3)	RWA	(1)	CUB	(3)	RWA	(1)
166	VCI	(1)	SDN	(1)	VCI	(1)	SDN	(1)
167	SOM	(1)	PNG	(0)	SOM	(1)	PNG	(0)
Set of countries	average in. degree		average out. degree		average in. strength		average out. strength	
Overall	94.0		94.0		641.4		641.4	
Bordering countries	110.6		158.0		2006.6		3849.6	
OECD countries	114.2		140.7		1443.6		1880.8	
BRICS countries	125.0		151.4		1981.8		1882.0	
Correlation	in. Degree		out. Degree		in. Strength		out. Strength	
in. Degree	1							
out. Degre	0.7580		1					
in. Strength	0.6642		0.7904		1			
out. Strength	0.4254		0.6721		0.8694		1	
log (distance)	−0.2285		−0.2890		−0.4153		−0.4806	
log (GDPpc)	0.5684		0.6194		0.8069		0.7047	

Countries are denoted by their three letter code following ISO 3166-1. All correlation coefficient are significant at the 1% level.

Table 2
Centralization indexes.

	Inward	Outward
Degree centralization	0.303	0.418
Strength centralization	0.032	0.070

nodes (*assortative* pattern), or to different nodes (*disassortative* pattern). Let us denote $\alpha_{u,d}$ the assortativity coefficient in direction d given by (unweighted) correlation coefficient between nodes degree and ANND. In 2011, French multinationals affiliates' network displayed a highly negative outward assortativity coefficient ($\alpha_{u,o} = -0.6569$, $p-$ value $= 0.000$), revealing a strong disassortative pattern in outward degrees connectivity. It shows that vertices with a large number of outward connection tend to connect to poorly connected ones. More precisely, core destinations (hubs) that give access to the largest number of further internationalization destinations, while those destinations only lead toward a few number of other destinations. So core countries give access in average to more peripheral countries, drawing a pattern of progressive integration of global value chains by multinational firms. The unweighted inward assortativity coefficient does not display such a disassortative pattern, with lower magnitude and significance ($\alpha_{u,i} = -0.1218$, $p-$ value $= 0.117$). Countries with numerous inward connections do not reveal a strong assortativity pattern.

In Fig. 3 we see that countries with higher outward degree are mainly OECD countries, as seen in Table 1. However, the figure also reveals that those OECD countries are afterward associated with less central countries, whereas the less central countries are in average associated with countries whose outward node degree is high. The inward assortativity being not very pronounced, no such pattern can be draw for inward connectivity.

To account for the arcs' weights, the average strength of all neighbors of a node i must be computed, referred as $ANNS_i$ index. The strength–strength correlation also displays an disassortative trend, although with a coefficient of ($\alpha_{w,o} = -0.227$, $p-$value $= 0.003$) the weighted outward disassortativity is lower than the unweighted one (in absolute value). This suggests that although they give more access to isolated countries, the most central nodes are more often associated to middle-central countries than to extreme peripheral countries. The scatter plot in Fig. 4 illustrates this disassortative weighted pattern of countries association, once again more pronounced in the outward direction. By studying every linkage simultaneously, the network analysis go beyond the traditional count flows analysis, and highlights a disassortative pattern of country linkage in FDI strategies, while focusing only on the principal associations first have tended to show that similar countries associations were preferred.

3.4. Three vertices correlation

Correlations between three vertices can be measured by the clustering coefficient (CC). It refers to the tendency for three vertices to form a complete triangle sub-graph. The binary unweighted CC of a vertex i is defined as $\gamma_i = \frac{2n_i}{k_i(k_i-1)}$ where n_i is the

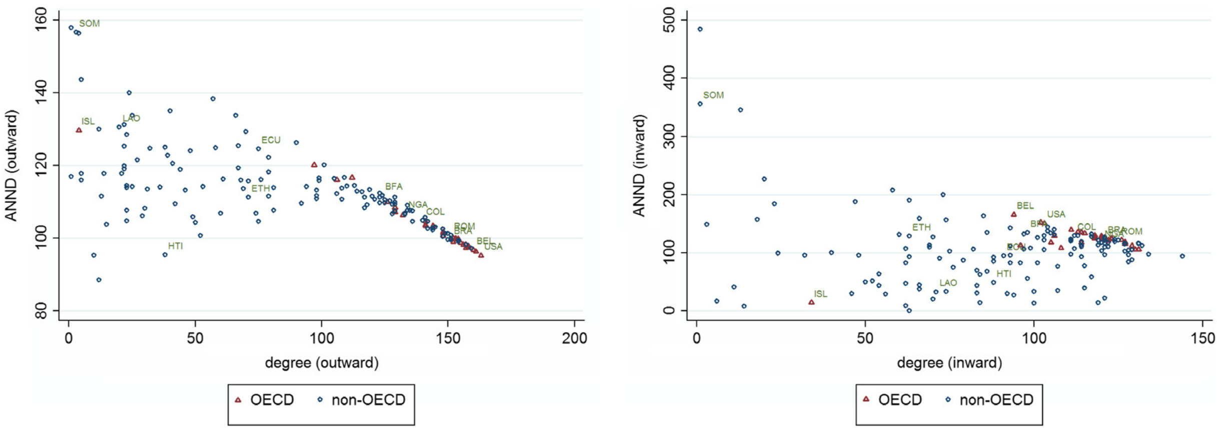

Fig. 3. Degree assortativity. Left panel: outward Degree assortativity. Right panel: inward Degree assortativity.

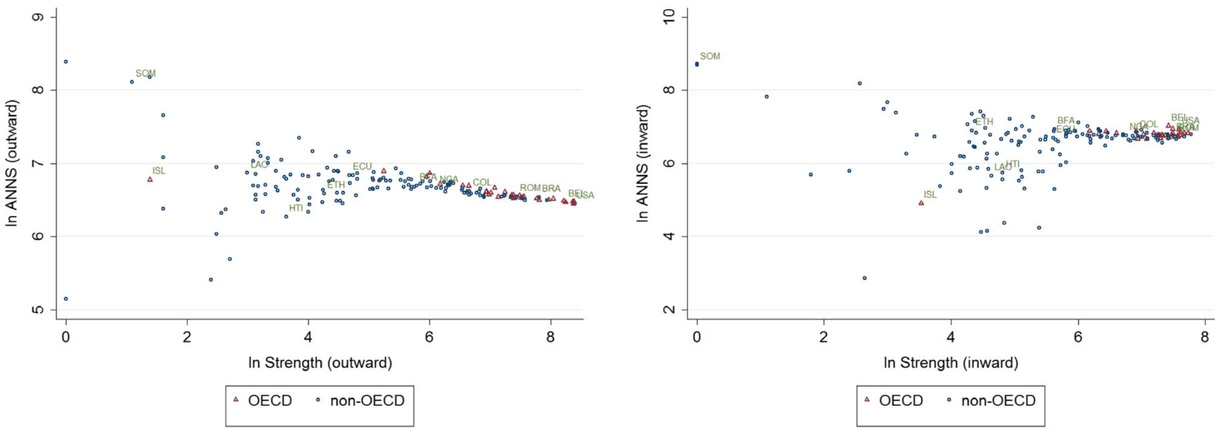

Fig. 4. Strength assortativity. Left panel: outward Strength assortativity. Right panel: inward Strength assortativity. Both ANNS and strength values are expressed in natural logarithm.

number of neighbor of *i* that are themselves connected to each other [17]. The overall CC reflects the ratio of closed triangles over all possible triangle subsets in the network. To conclude on the overall clustering level of the empirical network, it has been compared to the average overall CC of randomly drawn directed networks of the same dimension and density. The French multinational network has a very clustered structure, with an overall coefficient of 0.8544, versus 0.5662 in average for the null model.[5]

Several weighted extensions of clustering coefficient have been suggested as review Saramäki et al. [18]. I chose the Onnela et al. [19] index of weighted clustering coefficient, defined as the geometric average of subgraph edges' weights: $\tilde{\gamma}_i = \frac{1}{k_i(k_i-1)}\sum_{j,k}(\hat{w}_{ij}\hat{w}_{jk}\hat{w}_{ik})^{1/3}$, where $\hat{w}_{ij} = w_{ij}/max(w)$ is a normalized value of the edges' weights. This weighted clustering coefficient has some valuable features. It equals γ_i when the weights become binary and it is still bounded in [0; 1]. With an average of 0.2197 the weighted clustering coefficient displays much lower values than the unweighted one, because of the great variability of edges' weights within triangles. The concentration of weights on some edges also lead to a decrease of the clustering coefficient when weights are considered.

The empirical network investigated is not only weighted, but also directed. I therefore extend Onnela et al. index [19] to take direction into account, considering w_{ij} for outward weights from node *i* to *j*, and by w_{ji} for inward weights from *j* to *i*.[6] Table 3 summarizes the clustering coefficients computed. We observe that the inward clustering coefficient are always higher than the outward ones for both binary and weighted indexes, in line with above results showing higher outward

[5] Average based on 1000 random networks of dimension 167 and density 0.5663. The 90% confidence interval is [0.5656;0.5659]. The directed CCs are strictly similar, the direction of each arc being also uniformly distributed.

[6] A limitation of this index would be to only consider w_{kj} or w_{jk} for the weights between the two other nodes in the triangle sub-graph $((ijk))$, according to the direction considered in the CC of node *i*. It derives from taking symmetric elements in the weighted matrix for inward or outward nodes. For a proper discussion of all directed weighted clustering coefficients, see Ref. [20]

Table 3
Clustering coefficients for various specifications of the network.

	Undirected	Inward	Outward
Binary	0.8544	0.7400	0.6381
Weighted	0.2197	0.0237	0.0205

Table 4
MNEs' network characteristics over the years.

	2005	2006	2007	2008	2009	2010	2011	2005–2011 (% change)
1st order metrics								
Number of firms	2202	2236	2366	2264	2483	2649	2996	+36.0%
Number of affiliates	14202	15002	15516	14872	16904	18351	19872	+39.9%
Number of nodes	166	168	166	163	167	165	167	+0.60%
Number of arcs	12560	13283	13625	13924	14550	15001	15699	+25.0%
Density	0.4586	0.4734	0.4974	0.5273	0.5249	0.5544	0.5663	+23.5%
Average disparity (out.) $\bar{Y}_2$	0.765	1.962	2.186	0.770	0.387	0.246	0.284	−62.9%
(out.) $\bar{Y}_2$ Top 10 nodes	2.263	5.984	8.035	2.315	1.529	0.842	1.227	−45.9%
Degree centralization (out.)	0.4716	0.4634	0.4812	0.4508	0.4477	0.4177	0.4181	−11.3%
Strength centralization (out.)	0.081	0.079	0.075	0.072	0.071	0.070	0.071	−12.3%
2nd order metrics								
Degree assortativity (out.)	−0.498	−0.585	−0.691	−0.605	−0.605	−0.521	−0.654	−31.3%
Strength assortativity (out.)	−0.248	−0.240	−0.262	−0.258	−0.259	−0.256	−0.227	+8.4%
3rd order metrics								
Binary overall clustering	0.836	0.835	0.828	0.839	0.837	0.849	0.854	+2.1%
Weighted overall clustering	0.021	0.022	0.023	0.025	0.024	0.023	0.022	+4.7%
Binary outward overall clustering	0.603	0.609	0.608	0.618	0.610	0.624	0.638	+5.8%
Weighted outward overall clustering	0.019	0.020	0.023	0.023	0.023	0.022	0.020	+5.3%

than inward strength centralization. It implies a higher similarity in inward arcs than in outward ones. Also, the directed clustering coefficients are by construction lower than the undirected ones.

3.5. Evolution over time

Once observed the structure of the network, the immediate following question is about its stability over time. Is this hierarchical structure an exception or a durable characteristic of this network? Does the current wave of globalization, characterized by the expansion of multinational firms change this pattern? To investigate these issues, the network was reproduced from 2005 to 2011. Main network metrics are reported in Table 4.

At first, it should be noted that the network size did not change much in the considered time span, with a relatively stable number of nodes. A slight but notable drop occurred in 2008 and might be attributed to the economic crisis, which is also notable through the lower number of firms and affiliates this year, yet quickly overcame. Besides this relative size stability, the affiliates' network of French MNEs developed, gaining in density with an increasing number of actors (+36% of firms and +40% of affiliates in 7 years), and a growing number of countries associations, with nearly 57% of possible bilateral associations that are actually realized in 2011, against only 46% in 2005 as reveals the network density. It implies a decreasingly centralized network, as confirmed by the change in both degree and strength centralization indexes. The most central nodes lose progressively their superiority in the number of neighbors and the share of firms using them. This is consistent with the progressive diminution of assortativity coefficients, although only until 2011 for strength assortativity. The increasingly disassortative pattern indicates that the most central nodes are more and more associated to least central ones.

Another useful metric to look at the dispersion of flows within the network is the disparity index which measures the fluctuation in arcs' weights.[7] Not to be confused with strength centralization, the disparity focuses on arcs' weights, and no longer on nodes' strengths. A higher disparity implies that the node's strength is concentrated among few arcs, whereas lower disparity corresponds to a more fragmented flow between neighbors. The interpretation of outward directed version reported is straightforward. We observe a decreasing average disparity from 2007 to 2011. However the average disparity of all nodes blurs the great dispersion of disparity index among nodes. Focusing on the ten most central nodes (according to strength centrality) is more meaningful. The most central countries always display a higher disparity than the average because they have more linkages on which the weights could vary. However even the ten most central nodes experienced a decrease in the disparity among their neighbors of nearly 46%, although the tendency is not linear. Core countries in the network as the USA or France's bordering countries are more equally associated to all their neighbor in 2011 than they used to be.

7 Introduced by Barthelemy et al. [21]: $Y_2(i) = \sum_j (w_{ij}/s_i)^2$ and reported in Table 4.

Table 5
In/out ratios in 2011.

Overall	Mean in/out degree 1.60	Mean in/out strength 2.27
Bordering countries	0.70	0.53
Non-bordering countries	1.63	2.33
OECD countries	1.04	1.23
Non-OECD countries	1.74	2.53
BRICS	0.83	1.15
Non-BRICS	1.63	2.31
UE countries	0.86	1.25
Non-UE countries	1.74	2.46

Finally, all of the four specifications of the network overall clustering coefficient slightly increased between 2005 and 2011, implying greater number of complete triangle sub-graphs between three random countries, and more balanced ones. Several topological indexes (density, degree and strength centralization, disparity, clustering) converge in describing a world of increasing opportunities for French firms, with broader and more direct expansion possibilities, as well as an upsurge in new country associations in their international strategies.

4. Network building strategies

4.1. Inward/outward ratios and internationalization steps

As explained above, the inward degree gives the variety of countries that have preceded the expansion of MNEs in the observed destination. Conversely, the outward degree of the node indicates the number of countries where MNEs expand after an investment in the observed country. The ratio of inward over outward degree indicates thus whether the country has more destinations leading toward him than countries that it gives access to. Therefore, the in/out ratio indicates whether the country appears upstream or downstream the internationalization strategy, the lower the ratio the earlier the stage. Unlike in/out degree ratio that indicates the relative set of opportunity given by each node, the in/out strength ratio indicates how many firms enter the country before expanding elsewhere compared to firm that did the reverse path, picturing the relative frequency of each path.

Table 5 reports the value of these ratios for various set of countries from our empirical network. The overall mean in/out degree ratio is above unity (1.60), indicating that there is in average more paths toward a country than from it. At the opposite, we see that France's bordering countries have an in/out degree ratio lower than one, and much lower than non-bordering countries (respectively 0.70 versus 1.63). In line with this result, the in/out strength ratio is 4.4 times higher in the latter group. The pattern is similar, although smoother, when comparing OECD to non OECD countries. This suggests that neighboring countries and more generally developed (OECD) countries are often invested in the early stages of internationalization and then offer wide diversification opportunities. These findings are conventional enough with previous works on gradual expansion of MNEs. However, more surprising is the score displayed by the leading developing economies (BRICS). The mean in/out degree ratio of those five destinations lays between the neighbor and OECD scores, with a ratio of 0.83. A similar situation is observed for the weighted ratio. However this is no longer surprising when thinking at these countries as regional hubs. They act as gateways to regional market, and therefore display high score of outward degree, which decreases their in/out ratio. They do not come at the end of an internationalization but rather as a prequel for deeper diversification.

More generally, we observe a decreasing trend between a node's centrality index and the in/out ratios. The most central nodes appear then upstream the internationalization path, and diversification toward peripheral nodes comes afterward (Fig. 5[8]).

5. Firm heterogeneity and network building

5.1. Top productive and least productive firm networks

In this Section 1 built two distinct networks, respectively made of the 50% top productive firm's network (TPN) and 50% least productive firm's network (LPN). Because of data availability, I had to restrict the analysis to industrial firms, the only ones I could estimate their domestic productivity via the Levinsohn and Petrin [22] method based on EAE-industry survey data (*INSEE*). As a consequence, the sum of our LPN and TPN does not correspond to the previously examined network. Moreover, the EAE-industry survey stopped after 2007, which will therefore be the reference year from this section. At the first glance the TPN and LPN networks cannot be compared, because they do not share the same dimension (number of countries), nor the same density (number of affiliates in it). Indeed, it is known for long that foreign investment is the

8 I use the *closeness* index of centralization [10], based on walk a walk structure, independent from both nodes degree and strength.

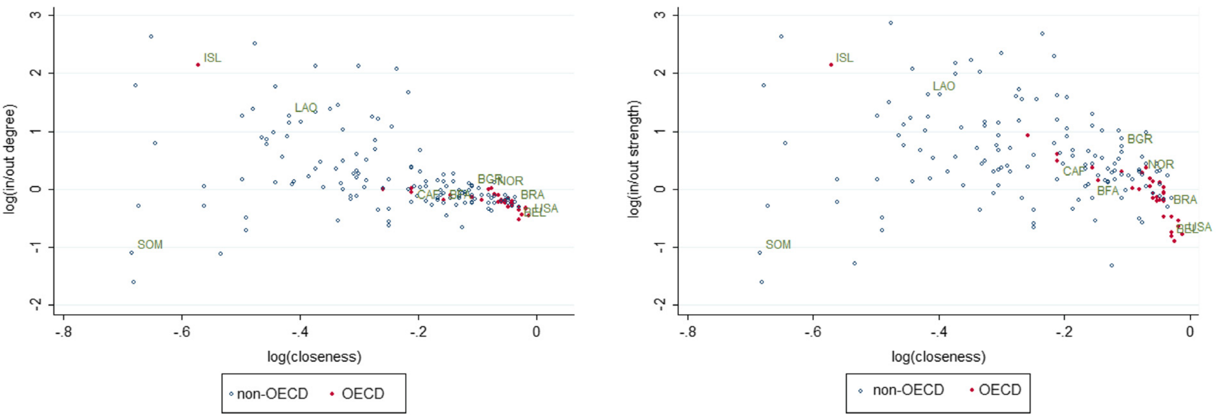

Fig. 5. Nodes centrality and in/out ratios.

prerogative of highly productive firms in the FDI versus arm's length trade trade-off [23,24]. Hence, we logically observe that the TPN has a higher density than the LPN. The TFP impact on location choice is also revealed when examining the nodes of each network. The set of countries present in both networks is mainly made of France's neighboring countries and then of other European countries and world leading economies as the USA or China. Top productive firms have a prerogative on 56 countries absent from the LPN. Those countries are in general more distant and less developed than countries observed in both networks (see Appendix B for the list details). Therefore, a brief analysis of these lists confirms the idea of a productivity-related location choice, with the more productive firms having access to the "tougher" markets [25].

5.2. *Firm heterogeneity and internationalization path*

Focusing now on the differences in in/out ratios between the two networks suggests that firm heterogeneity influences the internationalization path. As noted above, in/out ratios determine the countries' position in the internationalization path. Reported values in Table 6 reveal that France's bordering countries display an in/out degree ratio below unity for LPN, whereas higher than one for TPN. The strength ratio is below unity for both networks, but still lower in LPN. As a lower strength ratio indicates an earlier stage in internationalization path. The conclusion is straightforward: lower productive firms use more bordering countries in their early internationalization stages than more productive firms do. The exact same observation is made with the whole European Union, which appears more in upstream stages of internationalization for lower productive firms.

Another interesting difference is about the BRICS countries. For most productive firms, we see that they display lower degree and strength in/out ratio than non-BRICS countries (and lower to the overall mean). The BRICS appear then in relative early stages of internationalization, although the ratios are above unity. When focusing on the LPN though, the BRICS in/out ratios both outpace two, and are much higher than the ratio displayed in average, and for the non-BRICS countries. These high ratios indicate that twice more countries are preceding an expansion in a BRICS country than preceded by a FDI in them, and there is less than one on two MNEs coming into BRICS countries that have not pushed its expansion further ever since. BRICS countries appear then downstream the internationalization path, at the very end of expansion strategies for lower productive firms, whereas upper in the path for more productive firms. Conversely, insisting on similarities between the two sets of MNEs, we note that developed countries (OECD) appear in both networks in earlier stages of internationalization than developing countries. This finding though is more conventional, and in line with the gradual internationalization pattern of MNEs.

The comparison between the networks drawn by top productive firms and lower productive MNEs is instructive enough. First, it confirms previous results in the literature that insisted on the role played by TFP in the FDI decision and location choice. Then, the very network structure displays some differences, with a higher hierarchy for lower productive firms, whereas broader expansion opportunities for more productive MNEs, and less constrained path of development. Concerning this internationalization path, low productive firms appear to follow a more traditional pattern with neighboring and European countries upstream and leading developing countries downstream. These countries appear in earlier stages of internationalization of top productive MNEs as a premise of further expansion.

6. Concluding remarks

Applying a network analysis to look at the web of French subsidiaries in foreign countries provides interesting insights of the building internationalization strategy of multinationals. The first-order centrality measures confirm the central role of nearby countries and leading economies in multinationals expansion. However, the decreasing centralization trend

Table 6
In/out degree by productivity network.

	Top productive firms network		Least productive firms network	
	Mean in/out degree	Meanin/out strength	Mean in/out degree	Mean in/out strength
Overall	1.387	1.767	1.406	1.485
Bordering countries	1.029	0.914	0.744	0.782
Non-bordering countries	1.414	1.833	1.601	1.691
OECD countries	1.059	1.105	1.269	1.360
Non-OECD countries	1.568	2.136	1.701	1.752
BRICS	1.293	1.549	2.071	2.250
Non-BRICS	1.393	1.781	1.339	1.409
UE countries	1.013	0.982	0.696	0.761
Non-UE countries	1.482	1.967	1.737	1.823

highlights that French firms consider more and more peripheral countries as attractive destinations, and start spreading their network aside from the traditional core countries, as confirmed by increasing clustering coefficients. Second order metrics reveal that French firms tend to associate dissimilar countries in their FDIs, although the most frequent country pairs associate similar destinations.

Also the principal host countries in the network are shown to offer a wider set of further expansion opportunities than peripheral nodes. Those core nodes rather come in early stages of international expansion, with lower in/out degree and strength ratios, before a larger diversification. Interestingly enough some emerging economies are also shown to foster further internationalization.

Finally, this paper also provides some evidences that firm heterogeneity matters in multinationals' network construction, with lower productive firms following a more traditional and less varied internationalization pattern.

The network analysis suffers from some limitations though. The main one could be the absence of any causality evidences, especially concerning the role of firm heterogeneity in network structure, which calls for further theoretical work but also additional empirical evidences from other countries.

Appendix A. Strength centralization index

Based on the Freeman [16] definition of centralization, each centrality measure can have its own centralization index. Although the most commonly used is the degree centralization index, it is not properly adequate to study centralization of weighted network. I found no commonly accepted metrics for what I call "strength centralization", I therefore construct my own index following Freeman [16] methodology :

Let C_i be a centrality measure of the node i (i.e. either degree, or in what follows, strength), and C_{i^*} the maximum value of C_i in the network. The Freeman centralization index corresponds to

$$F_C = \frac{\sum_i^N [C_{i^*} - C_i]}{max \sum_i^N [C_{i^*} - C_i]}. \tag{A.1}$$

In reference [16], $max\sum_i^N [C_{i^*} - C_i]$ corresponds to the maximum possible sum of differences in point centrality for a graph of n points. I broaden this definition assuming it to be the maximum possible sum of differences in point centrality for a network of same dimensions (number of nodes and total weights).

Noting s_i the strength of node i defined as the sum of the weights of its arcs $s_i = \sum w_{ij}$, we have the strength centralization index by the formula :

$$F_s = \frac{\sum_i^N [s_{i^*} - s_i]}{max \sum_i^N [s_{i^*} - s_i]}. \tag{A.2}$$

Now let us try to determine the maximum sum of differences in the denominator. It is simple enough to see that the maximum possible value of s_{i^*} is the sum of the total weights $\sum_i \sum_j w_{ij} = W$ corresponding to a graph where all arcs are linked to one central node (and only it, e.g. the "star graph"). In the extreme case all other nodes will have the lower strength possible $min(s_i)$, such that the difference will be $W - min(s_i)$ for each of the $n - 1$ comparisons, thus the difference sum will be

$$(W - min(s_i))(n - 1).$$

As I said, the maximum possible sum of differences is reached for a star graph, where all weights are equal. In this case a node strength is only a proportional factor of its degree k, such that $s_i = min(s_i) * k$, and both degree and strength centralization indexes are equal to one.

The opposite extreme case consists in a perfectly decentralized graph, such as a "circle graph" where all nodes are linked to two neighbors and each arcs' weight the same (normalized to one). In this case, $s_{i^*} = s_i \;\; \forall i \quad \Rightarrow \sum_i^N [s_{i^*} - s_i] = 0$, the centralization index is therefore null.

Therefore, I suggest the following adaptation of Freeman index for the strength centralization:

$$F_s = \frac{\sum_i^N [s_{i*} - s_i]}{(W - min(s_i))(n-1)} \quad \text{(A.3)}$$

F_s has two appreciable properties: first is bounded between zero and one, the higher implying the greater strength centralization. Also, this index equals the standard degree centralization index when the graph is unweighted.

Appendix B. Productivity sub-sample appendix

B.1. List of countries in both TPN and LPN (29)

Austria; Argentina; Belgium; Brazil; Canada; China; Czech Republic; Germany; Great Britain; Hungary; India; Italy; Korea; Lebanon; Luxembourg; Morocco; Mauritius; Mexico; Netherlands; Poland; Portugal; Romania; Senegal; Slovakia; Spain; Switzerland; Tunisia; United States of America; Vietnam.

B.2. List of countries only in TPN (56)

Algeria; Australia; Bahrain; Benin; Bulgaria; Burkina Faso; Cambodia; Cameroon; Chile; Columbia; Congo; Cote d'Ivoire; Croatia; Cyprus; Denmark; Egypt; Finland; Gabon; Ghana; Greece; Guatemala; Iceland; Indonesia; Ireland; Japan; Latvia; Macao; Madagascar; Malaysia; Mali; New Zealand; Nigeria; Norway; Oman; Panama; Paraguay; Peru; Philippines; Puerto Rico; Russia; Saudi Arabia; Serbia; Singapore; Slovenia; South Africa; Sweden; Taiwan; Thailand; Togo; Trinidad and Tobago; Turkey; Ukraine; United Arab Emirates; Uruguay; Venezuela.

B.3. List of countries only in LPN (2)

Costa Rica; Malta.

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