Persistence in corporate networks through boards of directors? A longitudinal study of interlocks in France, Germany, and the United Kingdom

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Abstract:	This article studies, over the period 2006 to 2019, both the structure and the evolution of corporate networks built on shared board directors between the largest listed firms of three European countries: France, Germany, and the United Kingdom (UK). It offers a longitudinal and up-to-date analysis of the state of links between companies through examining interlocking directorates. Contrary to previous studies which have emphasized a decline of interlocks when analyzed at the board director level, we observe relative stability of these networks at the corporate level with a number of connected firms remaining quite stable despite a decline of board ties. As a result, the most central companies remain mainly the same at the national and international level over the considered period. Our findings provide evidence for the resource perspective: access to key resources seemingly pushes firms to continue their network participation despite strengthened national regulations on directors with multiple board seats. This evolution echoes the concept of weak ties of Granovetter (1973). Lastly, it is worth noting that it cannot be affirmed that there has been an emergence of a cross-national network which operates to substitute national board ties.

Persistence in corporate networks through boards of directors?

A longitudinal study of interlocks in France, Germany, and the United Kingdom

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ANSWERS TO REVIEWERS' COMMENTS	
Reviewer 1	
The manuscript reports a longitudinal research on interlocks in the three main European economies: France, Germany and the UK. Generally speaking, the manuscript conveys relevant research, built with sound methodology. The document would benefit from some minor changes, which I list below:	We greatly appreciate your time and the constructive comments and suggestions you have offered. As a response to your comments, we have significantly revised the entire paper.
1. In section 3.1 authors refer to institutional theory to account for homogeneity in interlock networks caused by coercive, normative and mimetic pressures. The title of the section and its opening are centered in coercive pressures coming from law, but along section 3 authors refer to facts like influence of governance codes and social pressures to add female directors, which I think they fall into normative pressures. Authors should take advantage of the flexibility of institutional theory to consider from the beginning normative and mimetic pressures to shape boards of directors. In this opening section authors may take advantage on literature of varieties of capitalism to account for differences in corporate governance between France and Germany on one side, and UK on another.	The structure of the theoretical section has been reviewed and the arguments have been further developed. A new section 2 "Theoretical frameworks" now provides an overview of the role of board director networks in both a resource perspective (2.1) and an agency perspective (2.2). In addition, we have improved the section on the influence of legal systems (2.3) on interlocks, while further developing the three types of pressures (coercive, normative, and mimetic). We now explicitly refer to literature on varieties of capitalism (Hall and Soskice, 2001) and the law and finance approach of La Porta et al. (1998) to explain differences in corporate networks between countries.
2. In the methodology section authors refer to two matrices: a so-called adjacency matrix with nonzero elements equal to the number of interlocks, and a binary matrix with values equal to one if there is at least one interlock in the previous matrix. Two observations here: first, in network theory it is usual to define the adjacency matrix as the one with 1s in the elements (i, j) when a relationship exists, and weights matrix to the matrix of values representing intensity of relationship. So I suggest authors to name adjacency matrix their M*, and weights M. Second, when analyzing the interlocks networks, authors use values obtained with binary values only, so maybe they can omit the weight matrix.	Following your suggestion, we have renamed weighted (M) and adjacency matrices (M*) accordingly, while adding a clearer description of the construction of both matrices in section 3. While we have decided to draw all network figures on the basis of weighted matrices to better visualize multiple ties, all our quantitative sociometric analysis have been run on the basis of adjacency matrices. This point has also been mentioned as a footnote under each table of results.
3. In Figure 1 are presented the temporal evolution of the number of interconnected firms. Maybe it should be more informative to present the fraction of interconnected firms, rather than the absolute value. For instance, in the present	As suggested, figure 1 has been changed and now represents, for each country, the fraction of firms that are interconnected. Absolute numbers of connected firms are presented in table 2.

Figure 1 France and the UK present a similar number of interconnected firms, while the number of firms is larger in the UK than in France (83/88 for France, and 84/97 for the UK).	
4. Either in the methods or in the results sections, authors should briefly explain why is their sample stopping at 2015.	To provide the most current picture of- corporate networks based on shared directors in the three countries of our analysis and among them (cross-border links), we have enlarged our observation period to 2019 (latest fiscal year with available data via BoardEx). As a consequence of the prolonged observation period, the size of all national samples had to be slightly reduced (less companies being listed in the mentioned stock market indices throughout the entire study period).
5. In section 6.2.2 authors speak of the "peak" of a network to refer to a vertex or node (p. 12, l. 12). I suggest omitting this, if authors do not have good reasons to maintain that, as it is not a common terminology in graph and network theory.	Thank you for this valuable comment regarding the use of the correct terminology. We have deleted the term “peak” accordingly.
6. When defining centralisation in section 6.3 authors state that the sum differences between maximum degree and actual degree across all nodes are divided by the number of nodes minus 1 (N-1). This is wrong: to normalise the measure, the mentioned sum is divided by (N-1)(N-2).	Following your comment, we have modified the description of the computation of centralization in the respective section. Degrees provided by Ucinet correspond to this definition.
7. When discussing central firms in each network, authors should comment the presence or absence of banks as more connected networks. A classical tenet of RDT is that firms bring directors from banking firms to ensure financial resources.	The role of financial institutions in board networks is now more clearly outlined in section 2.1 (Networks in a resource perspective). In addition to that, we now explicitly comment on their position and evolution in section 4 (Findings), and here specifically in subsection 4.2.2 (Centrality analysis). Lastly, we outline their gradual withdrawal from both national and transnational networks in sections 4.2 (Density and centrality analysis) and 4.5 (Cross-border networks).
8. When presenting central firms in the trans-national network, it may help to remember that Airbus is a trans-national company since its inception, and that this may drive its position in this network.	We have now explicitly highlighted the transnational nature of Airbus that may drive the company’s position in the cross-border network.
9. Typos detected: "ewe" for "we" in abstract (p. 1, l. 319). Maybe the title of section 3 "Influence of laws (...)" should be "Influence of law (...)" (if authors decide to keep it as is, see comment 1).	Thank you for your comments. To enhance clarity, its structure has been adapted and the respective sections and subsections have been renamed accordingly, proofreading of the paper has further allowed to eliminate as far as possible, typos as well as errors of grammar and punctuation.

Reviewer 2	
The paper analyzes the state of interlocking relationships between companies which give rise to networks. It is done for the countries France, Germany and United Kingdom for the period 2006-2015. The methodology of analysis of social networks is applied, and with the main theoretical framework of resource theories, trying to verify how the company networks have been able to change given the regulatory changes and if this decrease in national networks has been compensated with cross-border networks. It is observed, in general lines, how the national networks have been maintained (even increased) but with weaker relationships; and cross-border networks has not been increased. The paper is correct, it is well structured and presented, the methodology is correct and it should be noted that the social network analysis methodology is quite transparent. The topic itself is interesting, as it reflects the real state of relations between companies through interlocking. Several observations are made below with the aim of improving the quality and impact of the paper:	Many thanks for the constructive comments and suggestions you have offered. As a response to your comments, we have significantly revised the entire paper.
About the selection of the sample. There is not sufficient justification (perhaps there can be no justification) for the selection of the 2006-2015 period and neither of the countries. On the one hand, the years could reach the present. The social network analysis methodology, and what happens in this paper, is that it is descriptive. It is like a photo of how the situation is, but no conclusions can be drawn as to why, the origin or consequences of that network. Therefore, I advise at least having the most current photo possible, not only until 2015.	To provide the most current picture corporate networks based on shared directors in the three countries of our analysis and among them (cross-border links), we have enlarged our observation period to 2019 (latest fiscal year with available data via BoardEx). As a consequence of the prolonged observation period, the size of all national samples had to be slightly reduced (less companies being listed in the mentioned stock market indices throughout the entire study period).
Regarding the selection of countries, it is mentioned that each one represents a different model (mainly common-law and civil law), which is true. But then it would be advisable to make a brief introduction to the Law and Finance approach to point out that the different models can have an impact on the formation of networks (in fact, it is observed how the UK network differs from the others). It may even be that the board system (one tier or two tier) can have its effect as well (Germany has a two-tier model). I recommend seeing La Porta et al. 1998 and similar In this sense, the results themselves could be interpreted as an isomorphism, as pointed out by	We have entirely restructured section 2 (Theoretical frameworks) that now provides a clearer presentation of the role of board director networks in a resource (subsection 2.1) and an agency perspective (subsection 2.2), before offering an overview of the role of legal systems (2.3). In the latter, we present both the varieties of capitalism (Hall and Soskice, 2001) and the law and finance approach of La Porta et al. (1998) to explain differences in corporate networks between countries. In addition to that, specific aspects of national corporate governance systems (one tier vs. two tier board structure) are mentioned in the

Aguilera 2005 or convergence between models: Alcantara, D.B 2012, in part due to the codes and regulations.	introduction and in section 4.4 (Influence of regulation).
Regarding theorical approach: Put a more current reference when mentioning in the introduction possible articles of interlocking directorates in corporate governance (now only 2005 and 2011 appear). In fact, it is recommended to show articles from both streams on possible effects of networks on companies: on the one hand, positive effect, mainly based on resource theory, but there are also authors who indicate a possible negative effect (derived for example from busy directors) I recommend seeing Larcker et al. 2013; Andrés et al. 2013; Blanco-Alcantara, D. et al. 2019 among others. This would allow the theoretical framework to be further developed.	Alongside the restructuration of section 2 (Theoretical frameworks), we have more clearly emphasized potential positive and negative effects of board interlocks while including in parallel more recent references (i.e., Buchwald 2014; Homroy and Slechten 2019; Buchnea et al. 2020 and Omer et al. 2020 in addition to those you suggested). We have furthermore integrated into subsection 2.4 a table synthesizing relevant empirical research on board director networks (from a corporate perspective) in our three countries and for cross-border samples, while highlighting their respective key sociometric results.
Regarding methodology and results: The degree centrality measure is applied, but the betweenness and closeness measures could also be applied (the 3 are also valid for company level). And it is advisable to add a table with the most central companies based on these measures (with their values) and their evolution. It could help to visualize the changes experienced in the network.	Following your suggestions, we have enlarged section 4.2 (Sociometric analysis) by an analysis of betweenness and closeness centralities of our sample firms. In addition to that, we have created two tables presenting, for each of the two additional centrality measures, the most central companies and their evolution over time.
Erratum in the abstract, in the last sentence: Finally, ewe find no evidence… (must be we)	Thank you for your comment. Proofreading of the paper has allowed to eliminate, as far as possible, typos as well as errors of grammar and punctuation.

Persistence in corporate networks through boards of directors?

A longitudinal study of interlocks in France, Germany, and the United Kingdom

Abstract

This article studies, over the period 2006 to 2019, both the structure and the evolution of corporate networks built on shared board directors between the largest listed firms of three European countries: France, Germany, and the United Kingdom (UK). It offers a longitudinal and up-to-date analysis of the state of links between companies through examining interlocking directorates. Contrary to previous studies which have emphasized a decline of interlocks when analyzed at the board director level, we observe relative stability of these networks at the corporate level with a number of connected firms remaining quite stable despite a decline of board ties. As a result, the most central companies remain mainly the same at the national and international level over the considered period. Our findings provide evidence for the resource perspective: access to key resources seemingly pushes firms to continue their network participation despite strengthened national regulations on directors with multiple board seats. This evolution echoes the concept of weak ties of Granovetter (1973). Lastly, it is worth noting that it cannot be affirmed that there has been an emergence of a cross-national network which operates to substitute national board ties.

Keywords: interlocking directorates - board interlocks - corporate networks - resource based view - resource dependence theory

1 Introduction

Interlocking directorates (or "board interlocks") have long been subject to studies in sociology and strategy (Mace 1971; Zeitlin 1974; Useem 1979), and since the 1990s also in corporate governance (Prinz 2011; Andres et al. 2013; Larcker et al. 2013; Buchwald 2014; Blanco-Alcantara et al. 2019). As defined by Mizruchi (1996, p. 271), interlocks "occur when a person affiliated with one organization sits on the board of directors of another organization". Until the mid-1990s, most scholars have observed – irrespective of the underlying theoretical approach – a high concentration of such links (with varying degrees depending on the country), particularly in Continental Europe. A rather small circle of individuals thus appeared to concentrate in their hands numerous board seats in France (Windolf 2002; Chabi and Maati 2005, 2006), Germany (Pfeiffer 1993; Windolf and Beyer

1996; Andres et al. 2013), Spain (Aguilera 1998; Blanco-Alcantara et al. 2019) and Italy (Simoni and Caiazza 2012), but also transnationally in Europe (Maati 2008; Cárdenas 2012; Buchwald 2014).

From a corporate perspective, the formation and the persistence of board networks might be explained by resource theories, the resource dependence theory and the resource-based view. Through multiple directorships, board members provide firms with critical resources, and this contributes to their sustainability (Mizruchi 1996; Jonnergård and Stafsudd 2011; Larcker et al. 2013; Caiazza et al. 2019; Homroy and Slechten 2019; Wang et al. 2019). The negative effects of interlocking directorates are also studied in literature, with scholars mainly adopting an agency perspective and findings showing weaker monitoring of firms with busy directors (Fich and Shivdasani 2006; Andres et al. 2013; Larcker et al. 2013; Blanco-Alcantara et al. 2019).

Since the turn of the century, a strengthened orientation towards shareholder value seems to have caused a sensible change in board links (Hall and Soskice 2001). Interlocking directorates have reduced in several European countries (Beyer and Höpner 2003; Heinze 2004 for Germany; Prinz 2011 for France and Germany; Drago et al. 2015; Fattobene et al. 2018 for Italy; Buchnea et al. 2020 for the UK) and elsewhere (Carroll and Klassen 2010 for Canada, the United States (US), Europe, and Japan; Chu and Davis 2016 for the US), the scope of the evolution varying across countries. Corporate governance practices are constrained by institutional settings, including regulation (Windolf 2002; Carroll and Klassen 2010; Drago et al. 2015). Networks are shaped by national legal systems, where a distinction is made either between common-law or civil-law countries (La Porta et al. 1998) or, depending on the variety of capitalism of the country, between liberal and coordinated market economies (Hall and Soskice 2001).

In this study we consider networks at the corporate level and analyze the evolution of company connections through examining shared board members. Our analysis covers a 14-year period (2006-2019) and involves a detailed comparative overview of corporate links in three countries: France, Germany, and the UK. Besides being the biggest European economies, our sample countries represent the different legal traditions suggested by La Porta et al. (1998) as well as the two types of economies studied by Hall and Soskice (2001). In addition, these countries represent different governance systems: the UK with a one-tier board system where CEO duality is rare; Germany with a two-tier board system based on strict separation between management and supervisory boards, and France which offers firms more flexibility with respect to governance structure they apply. Taken together, these aspects constitute different frameworks for corporate networks, and these might influence their formation, shape and evolution.

The contribution of our study is four-fold. Firstly, by using the network data analysis software *Ucinet*, we provide an up-to-date picture of corporate networks based on board interlocks in three European economies and highlight their key differences. Secondly, running an analysis over 14 years, we contribute to the literature on the evolution of board interlocks and consider the impact of changing national regulation on multiple board seats. Our study thirdly supports the resource perspective in that we observe over time relative stability in the number of connected firms, despite a declining level of board ties, suggesting that firms continue to maintain access to critical resources despite strengthened regulation of board directorships. Lastly, our study highlights that the quantitative decline of national board ties does not lead to a substitution for cross-border board links between the three sample countries, thereby not confirming previous studies about the emergence of a Pan-European network of board interlocks.

The rest of the paper is organized as follows. Section 2 presents the theoretical framework, the influence of legal aspects on interlocks, and a synthesis of relevant studies. Section 3 describes our data and the methodology. Section 4 offers a detailed overview of our findings. Discussion and conclusion take place in section 5.

2 Theoretical frameworks

2.1 Corporate networks through boards in a resource perspective

Granovetter (1973) highlighted the interaction between social life and economic activities, showing that firms are tied within a network of relationships that influence their actions and results. Various approaches have since emerged to explain why corporate networks through boards exist, considering these from either an individual or an organizational angle. At the individual level, the management control model, the class hegemony model or the career advancement model are often used to explain both the role and nature of board interlocks. At the organizational level, interlocks are seen "as a relation between institutions" (Drago et al. 2015, p. 40), and related studies are often based on the resource dependence theory (Pfeffer and Salancik 1978) or the resource-based view theory (Wernerfelt 1984); both consider resources as a key input factor for firms seeking to meet their strategic objectives.

Following the resource dependence theory (RDT), the power and survival of a firm are mainly determined by critical resources such as capital, raw materials, or information (Pfeffer and Salancik 1978). Given that these resources mostly cannot be sourced internally, firms are forced to interact with external actors to assure their access to them. Aiming to reduce the environmental uncertainty that this dependence engenders, firms use various cooptation instruments among which the board of directors stands out (Pfeffer 1987; Yeo et al. 2003; Blanco-

Alcantara et al. 2019; Wang et al. 2019). Given that board members provide firms with information on markets, environment, regulation, governance, technology, improve terms of contracts and might be sources of new business relationships, one may argue that shared board directors between companies stimulate the information flow between the linked firms, provide mutual advantages and thereby enhance their external resilience (Larcker et al. 2013; Wang et al. 2019). Consequently, interlocking directorates are seen as relationship management tools that enable firms to develop connections with their external environment and thereby to secure critical input factors (Mizruchi 1996; Carpenter and Westphal 2001; Fattobene et al. 2018; Caiazza et al. 2019). Providing connected actors with a better scan of their business environment, board interlocks contribute to reduced competition and uncertainty, and thereby strengthen the strategic position of the involved firms (Conyon et al. 2011; Wang et al. 2019). Capital usually features at the top of the list of firm's critical resources and represents a major motive to share directors, the argument being that board links to financial institutions provide a better and cheaper access to capital and thus improve the firm's overall performance (Yeo et al. 2003; Jonnergård et al. 2004; Drago et al. 2015; Fattobene et al. 2018). Accordingly, higher financial dependence is supposed to lead to more numerous board interlocks (Mizruchi and Stearns 1988). As a result, banks often become central actors in corporate board director networks (Davis and Mizruchi 1999).

While the resource-based view theory (RBV) also considers a firm's setting of resources as decisive for its competitive advantage and long-term success, the approach applies a more dynamic logic focusing on the cognitive interactions of the firm's decision makers to create unique knowledge and valuable skills (Wernerfelt, 1984; Barney 1991). Consequently, RBV attributes an active and strategic role to the board of directors, such as encouraging and managing organizational learning through a valuable combination of resources, leading to better problem-solving capacities (Macus 2008). In light of these considerations, board interlocks can be seen as specific instruments – valuable and non-substitutable resources related to linked external actors – that actively contribute to a firm's value creation process (Powell 1990; Contractor et al. 2006; Conyon et al. 2011; Youn et al. 2016). They do so by broadening a firms' ability to access external information, knowledge and expertise in fields such as strategy, governance, internal organization or corporate social responsibility (Chisholm and Nielsen 2009; Adams et al. 2010; Prinz 2011; Jonnergård and Stafsudd 2011; Brennecke and Rank 2017; Caiazza et al. 2019; Wang et al. 2019) and thereby stimulate the overall organizational outcome. Greater board experience of members with multiple directorships further enables a better evaluation of a firm's strategic positioning (Baysinger and Hoskisson 1990; Geletkanycz and Hambrick 1997; Carpenter and Westphal 2001) and thereby also contributes to better overall performance.

2.2 Corporate networks through boards in an agency perspective

Although agency theory sometimes considers directors with multiple mandates as having more monitoring experience (Ferris et al. 2003; Fich and Shivdasani 2006), most of the studies adopting an agency perspective emphasize negative performance effects of corporate networks based on common board directors, highlighting that networks lead to lower monitoring and create conflicts of interest for companies sharing directors (Fich and Shivdasani 2006; Andres et al. 2013; Blanco-Alcantara et al. 2019). Directors with multiple external board seats are considered as too "busy", lacking time for preparing and attending meetings and to efficiently assure their monitoring role (Ferris et al. 2003). Multiple directorships, particularly when reciprocal, are more likely to reduce independence and quality of board decisions due to conflicting objectives and roles (Fich and White 2005). Multiple directorships may negatively affect governance practices through, for instance, higher executive pay levels or lower turnover in case of bad performance (Fich and White 2003), and accounting irregularities (Omer et al 2020). Interlocks may also cause higher risks of collusion resulting in lower competition pressure and the conclusion of agreements between the connected firms at the detriment of consumers (Caiazza et al. 2019; Thépot 2022).

2.3 Influence of legal systems and varieties of capitalisms on corporate networks through boards

The effects and scope of corporate governance mechanisms are determined by national institutions (La Porta et al. 1998; Hall and Soskice 2001; Aguilera and Jackson 2003;). Firms are embedded in systems of norms and rules that can exert different kinds of pressures on them: coercive, normative or mimetic, all leading to isomorphism (DiMaggio and Powell 1983). While coercive pressures relate to instruments, such as laws, with penalties obliging firms to comply with the rules, normative pressures comprise professional or social norms or standards that are said to lead to homogeneous practices (Scott 1995). Mimetic pressures refer to firms adopting the practices of other companies because they view them as more efficient (Aguilera and Jackson 2003). All three types of pressures may contribute to shaping corporate networks based on shared board directors.

Among institutional settings, regulation is recognized as influencing corporate networks, determining their structure and nature (Cárdenas 2012). The influence of regulation on board networks depends on its type, the influence being stronger in the case of hard laws (compulsory rules with penalties in case of non-compliance) that provide coercive, normative and mimetic pressures (Luoma and Goodstein. 1999), than with soft laws (non-binding instruments such as codes and recommendations), associated with only normative and mimetic pressures (Allemand et al.

2021). Accordingly, declines in interlocks may be caused by evolving regulation with specific laws restricting i.e., the size of boards or the number of seats directors can cumulate (Windolf 2002; Carroll and Klassen 2010; Drago et al. 2015).

Two main classifications of legal systems are usually put forward in the literature on governance: the law and finance approach (La Porta et al. 1998) and the varieties of capitalism approach (Hall and Soskice 2001). The first suggests distinguishing between common law (English in origin and shaped by precedents from judicial decisions) and civil law (Roman in origin, corresponding to French and German traditions and characterized by statutes and codes, relying on legal scholars to formulate the rules). La Porta et al. (1998) provide evidence that laws and their enforcement concerning investors' protection are strong in common law countries, intermediary in German civil law countries, and the weakest in French civil law countries, in which ownership concentration substitutes for laws as governance mechanism. These legal traditions have also influenced the formation of networks, with historically more developed networks in French civil law countries than in common law countries (Andres et al. 2013). When shareholders' rights are weak, the development of networks seems to be a way for senior managers and directors to extract value from the company, which could explain why board networks are more important in civil law countries. The second approach frequently used to account for differences across legal systems is the distinction based on varieties of capitalism between liberal and coordinated market economies (LMEs and CMEs). In LMEs, economic coordination is thought to rely on competitive market arrangements, whereas in CMEs coordination is said to rather depend on nonmarket relationships, such as network monitoring or collaborative relationships, reflecting strategic interactions among actors. Firms in France and Germany, examples of CMEs, might therefore have developed more networks than companies in the UK belonging to LMEs, since they traditionally coordinate through relationships. Despite these justifications for differences in national networks, several scholars suggest that national corporate governance systems may converge in a context of increasing globalization and in light of the spread of codes and good practices all over the world following numerous governance scandals and financial crises' (Aguilera 2005; Alcantara et al. 2012). Therefore, this shift could lead to a homogenization in the characteristics of corporate networks based on board directors between countries.

2.4 Main findings of studies on board networks in France, Germany, the UK, and across borders

Over the last twenty years, many studies have been conducted on networks based on common board directors in France, Germany, and the UK, with some analyzing, in addition, cross-border links (table 1). Given that each study works with different sample sizes and observation periods, comparisons of sociometric indicators (that increase

mathematically when sample sizes decrease) for a given country and even more between several countries appear difficult.

Yet, four major conclusions about the evolution of board director networks can be made. Firstly, there seems to be an overall trend toward fewer board ties and lower density levels, this effect being less important for the UK (Homroy and Slechten 2019; Buchnea et al. 2020) and more generally for smaller samples consisted of the biggest companies (Heinze 2004; Prinz 2011; Van Veen and Kratzer 2011; Allemand and Brullebaut 2018; Buchnea et al. 2020). Secondly, the share of linked companies noticeably decreases in Germany from historically high levels while it remains quite stable over the last two decades in both France (Chabi and Maati 2005, 2006; Ben Barka and Dardour 2015; Allemand and Brullebaut 2018) and the United Kingdom (Windolf and Nollert 2001; Buchwald 2014). Networks based on shared board directors therefore seem to downsize over time in all three countries, whereas the fraction of connected companies diminishes less rapidly (Germany) or remains quite stable (France and the UK). Thirdly, all three countries show, at least for samples of the biggest firms, the existence of one large component covering all or most interconnected firms (Chaabi and Maati 2005, 2006; Prinz 2011; Van Veen and Kratzer 2011). Finally, financial institutions still seem to take a key role as central actors in the network of board interlocks in Germany and France (Windolf and Beyer 1996; Windolf and Nollert 2001; Heinze 2004; Chabi and Maati 2005, 2006), although this trend has not been mirrored (anymore) in the UK (Windolf and Beyer 1996; Buchnea et al. 2020).

Given the increasing globalization of business, and the rise of regulations on boards at national level, companies may be tempted to substitute national with cross-border director links (Carroll et al. 2010b; Van Veen and Kratzer 2011). Studies broadly show that transnational connections remain quite marginal compared to national interlocks (table 1), both at the European (Carroll and Fennema 2002; Kentor and Jang 2004; Carroll et al. 2010b; Buchwald 2014) and the global level (Heemskerk and Takes 2016). Cross-border links between firms increase at moderate pace over time in France and in the UK, and even decrease in Germany (Buchwald 2014). In addition, studies on cross-border networks find contrasting results regarding dominating actors, highlighting both industrial firms (Carroll and Fennema 2002) and financial groups (Carroll et al. 2010b) as central actors. Given that most of the identified studies on national and international interlocks are based on data from before 2014, an up-to-date picture of board director networks seems necessary to gain further knowledge about the evolution of board director networks in light of ongoing globalization.

[Insert table 1 about here]

3 Data collection and methodology

Our aim is to analyze both the structure and the evolution of corporate links through boards in the three largest European economies[1]: France, Germany, and the UK. Our sample covers the board members of all firms that have been continually listed in major national stock indices during the period 2006-2019: 82 companies from the SBF 120 index for France, 85 groups from the indices Dax30, MDax, TecDax, and SDax for Germany, and 83 firms out of the FTSE 100 index for the UK. For the 14-year observation period, our three national samples include in total 2,382 board directors for France, 3,369 for Germany, and 2,013 for the UK.

We have collected the names of all board members of the sample firms from the database BoardEx[2] and cross-checked with information from annual reports. To identify board ties, we have then picked board members common to two firms ("busy directors") for a given year. Based upon this data, we have built two types of squared matrices for each year: weighted matrices (M) and adjacency matrices (M*). The first type (M) shows in each cell the number of board members two companies i and j have in common[3], an approach applied in several previous studies (Aguilera 1998; Romano and Favino 2013). Weighted matrices enable to identify the weighted graphs of links through boards whereas nodes are the companies and every pair of companies ij is linked by an edge whose value equals the number of common board members. Accordingly, weighted matrices exhibit the intensity of the relation between firms. The second (M*) type applies a binary logic as cells only provide information about the existence or absence of links: if two companies i and j have at least one board member in common, the corresponding cell takes the value one, otherwise the cell is assigned the value zero. Adjacency matrices thus illustrate the pure existence of links between firms, disregarding the strength of these ties.

For both types of matrices, companies (nodes) are considered more central within a network as their total links (degrees) to other firms increase (Freeman 1978/79). We have generated, for both types, a total of 42 squared matrices, one for each country and year of our sample. Applying the same logic to cross-border ties, we have additionally built fourteen tri-national matrices comprising all companies of the three national samples (250 firms in total). To avoid any misinterpretation of national data while studying the cross-border sample, we have deleted intra-national links to only retain transfrontier ties. Aiming at conducting an in-depth analysis of the characteristics of the networks, we have used the software *Ucinet 6* (Borgatti et al. 2002) which enables us to depict networks on a yearly basis and to compute socio-metric indicators such as density, centrality, or centralization.

[1] European refers to the EU, the UK being part of the EU throughout all the period covered by the sample.
[2] Database offering information on boards and executives in European companies, http://corp.boardex.com
[3] For example, the intersection of column i (company A) and of row j (company B) shows the number of common directors to companies A and B for the given year.

4 Findings

4.1 Descriptive statistics

While in each country the total number of ties between companies has dropped significantly (-29.9% in the UK, -44% in France, and even -62.9% in Germany), this decrease appears mainly due to the reduction of the number of ties per connected company rather than the reduction of the number of connected firms (table 2). The reduction mostly takes place at the individual level, with a considerable drop of the number of directors having multiple seats in the three countries (-20% of busy directors in France, -45.3% in Germany, and -22.7% in the UK). As a consequence, the average level of links a firm maintains with its pairs dropped over time from 4.24 in 2006 to 2.37 in 2019 in France, from 3.45 to 1.46 in Germany thereby achieving levels similar to the UK (cutback from 1.81 to 1.38). The sharp decline of interlocks corroborates previous trends observed in Germany (Heinze 2004; Buchwald, 2014), and in the US by Chu and Davis (2016). The reduction of ties may be explained by factors such as a tendency of board size reduction, change in ownership patterns, as well as by a search for greater diversity and independence of directors (Ferreira and Kirchmaier 2013, Buchnea et al. 2020).

Despite the observed sharp cutback of individual ties in all three countries, the number of interconnected firms (figure 1) stays stable over time (±0% in France with more than 90% of the firms being connected in 2019 within one single component) or only shrinks at lower pace (-12.3% in Germany and -8.1% in the UK for the period, representing an annual decline of less than 1%). Following the resource perspective, this resistance of corporate networks may reflect that even in a context of ongoing reductions of board ties at the individual level, firms manage to maintain their connections to provide access to critical resources. Accordingly, the shape of the corporate networks based on common board directors in our sample countries seems to rely on what Granovetter (1973) called "weak ties": connections formed via a dispersed and extended network that are considered being more effective for the flow of information and the promotion of innovation.

[Insert table 2 about here]

[Insert figure 1 about here]

4.2 Density and centrality analysis

Using *Ucinet 6*, the visual presentation of the board director networks in France and the UK (figures 2 and 3) reveals a giant component. Accordingly, among connected firms, all French and almost all British companies make up part of one single national network (four interconnected firms outside the large component in 2006 and three in 2019), the level of

network coverage of interlocked groups staying stable in France (100%) and even slightly increasing in the UK (94.6% in 2006 and 95.6% in 2019). In contrast to this, the German network has experienced more significant changes over time. While in 2006, only two groups were linked to each other outside the core component, their number has increased to 13 in 2019. In parallel to that, the share of interlocked firms belonging to the main component drops from 96.9% in 2006 to 77.2% in 2019. Even though all national networks become visually looser over time, our findings thus suggest that the overall decrease of the number of board ties does not have the same structural effects in each of the three countries. While the quantitative reduction of board interlocks barely affects the integration capacity of the networks in both France and the UK, the observed bigger cutback of board ties in Germany seemingly results in an initial thinning of the giant component. That said, our results broadly confirm for all three countries that most firms remain connected to other peers, but through a reduced number of ties and weaker ties.

[Insert figure 2 about here]

[Insert figure 3 about here]

4.2.1 Density analysis

Density (or connectivity) of a network quantifies the relevance of the existing ties between all actors compared to their theoretical maximum. It is computed by dividing the sum of all ties by the total number of possible ties within a network, with values ranging from zero (lowest density) to one (highest density). Applied to board interlocks, the number of possible ties is calculated by multiplying the number of companies (N) by that same number minus one (N-1). As pointed out by Esposito de Falco et al. (2018, p. 11), the "indicator describes the part of potential connections that is effective". Accordingly, high density is seen as a proxy for greater integration and related opportunities to coordinate interests (Cárdenas 2012).

Our findings (table 3) partially corroborate Cárdenas' (2012) conclusions on cohesive networks in France and Germany and dispersed networks in the UK. As our samples are larger, adjacency matrix-based densities in all three countries are mechanically lower but their comparison still reveals a lower 14-year average density in the UK (0.017) than in France (0.039) or Germany (0.023). In 2006, Germany's board network density (0.031) was closer to the UK's (0.020) than to the one of France (0.048). Given the comparatively bigger cutback of board ties in Germany, this gap becomes larger over time, with density levels falling below those of the UK from 2018. Contrary to expectations, in France, where the regulation on board interlocks is the strictest, the density remains the highest even if it also decreases by 44% during the period.

[Insert table 3 about here]

4.2.2 Centrality analysis

The concept of centrality is generally used to assess the strength of the position of each actor (node) in a network, meaning their potential of influence (Wang et al. 2019). Commonly used measures are degree centrality, closeness centrality, and betweenness centrality (Freeman 1978/79).

Degree centrality

Degree centrality measures the number of direct links a node has with others within a network (Freeman 1978/79). It is computed as a percentage ranging between 0% (no link to any other node) and 100% (links to all other nodes). The higher the centrality degree of a node, the more central its position. Related to board interlocks, degree centrality allows the identification of the most connected companies. To estimate degree centralities, we use adjacency matrices and count one relation between company i and company j if they share one or several common board directors. For each company, the sum of all existing ties to other firms was then standardized (meaning divided by the total number of firms minus one) and expressed as a percentage.

[Insert table 4 about here]

Overall degree centrality, while decreasing (particularly at centrality levels ≥7.5%), remains noticeably higher in France than in Germany and the UK (table 4). No more firms have a degree centrality of ≥20. Nevertheless, over the entire period, only one French firm (ALTEN) was never linked to peers (degree centrality of 0%). Considering a 14-year average of degree centrality, eight companies are in the top ten for at least eight years (BNP Paribas, Bouygues, Engie, Eurazeo, Imerys, Renault, Total, and Veolia). While the ten most central groups have lowered their board ties by about 46% during the observation period (from 145 in 2006 to 79 ties in 2019), the French network as a whole though did not reduce its width, integrating in 2019 as many firms as in 2006. Consequently, decreasing degree centralities seemingly do not have significantly affected the overall shape of the corporate network of board directors in France.

Compared to France, the decline in degree centrality is sharper in Germany, the median being divided by three during the observation period (3.6% in 2006 vs. 1.2% in 2019) and levels ≥15% having disappeared since 2016. Consequently, the number of companies with a degree centrality equal to 0% increased over time by 40% from 20

to 28 firms (while there was no change in France). Eleven firms have never been linked to any other sample company during the entire 14-year period. Despite the drastic decline in degree centrality, the composition of the network core, however, did not alter significantly, thus suggesting a relative stability of the center over time which we also observed for France. Considering a 14-year average degree centrality, all top ten firms (Allianz, Bayer, BMW, Daimler, Deutsche Bank, Deutsche Lufthansa, Henkel, Linde, RWE, and Siemens) figured in at least eight years among the annual top ten most central groups. While these firms reduced their board interlocks over time by 60.4% (from 159 ties in 2006 to 63 in 2019), that sharp reduction seemingly did not cause key changes in the core group. Consequently, our results confirm observations from Heinze (2004) and Prinz (2011) of a progressive thinning of the German network of board interlocks without destroying the qualitative structure at its core.

Similar to France and Germany, the median degree centrality in the UK sinks over time although ends, due to a lower decline pace, at higher levels than the German one (2.4% vs. 1.2% in 2019). In line with the observed fall, the number of British companies with a degree centrality of 0% increased over time by two-thirds (from 9 to 15 firms), two of them (Antofagasta and JD Sports Fashion) never sharing board directors with national peers during the observation period. With only one company (Sainsbury's) showing a degree centrality ≥7.5% in 2019, no firm seems to be pivotal in the British network even though a relative stability of the most central firms can be seen over time. When looking at the 14-year mean degree centrality, seven firms figure in the top ten in at least eight years (3i Group, BP, Reckitt Benckiser Group, Kingfisher, National Grid, Standard Chartered, and Vodafone) and three in at least ten years (BP, Reckitt Benckiser Group, and Standard Chartered). Even though the most central firms reduced their board ties at a comparatively higher pace (-50.7% between 2006 and 2019) than the entire national network, the stability of the composition of the core component of board interlocks over time is remarkable.

To sum up, despite sinking degree centralities, the number of connected firms stays stable (France) and only slightly falls over time (Germany and UK). No major changes can be observed in the national network cores where central actors tend to maintain their position with a lower number of links. Contrary to previous studies (Yeo et al. 2003; Jonnergård et al. 2004; Drago et al. 2015; Fattobene et al. 2018), banks do not dominate in any country as the most central firms. The respective top ten national firms only comprise one or two banks (BNP Paribas in France; Deutsche Bank in Germany; Lloyds Banking Group and Standard Chartered in the UK). The number of firms connected to banks has sharply decreased during the observation period (BNP Paribas from 18 to 8, Deutsche Bank from 17 to 4, Lloyds Banking Group from 8 to 2 and Standard Chartered from 9 to 5). This trend confirms the results of previous studies (Morin and Rigamonti 2002; Beyer 2003; Carroll et al. 2010b; Buchnea et al. 2020) according to

which this type of trend could be explained by better access of firms to capital markets and a reduction of bank ownership in firms.

Closeness centrality

Closeness centrality measures how quickly a node can reach other nodes by using the shortest path (Freeman 1978/79). The higher a node's closeness centrality, the more central the node is with respect to others. Related to board interlocks, closeness centrality enables us to identify companies with the shortest distances to others. It corresponds to the inverse of the sum of the geodetic (shortest) distances between that company and all other firms. In case of unconnected graphs, it is recommended to estimate the harmonic centrality index (Rochat 2014). This proximity index is computed by dividing the sum of the inverted geodetic distances by the sample size minus one. Companies with low harmonic centrality values are situated at the periphery of the networks and firms with high index levels in the center of the networks.

French companies have, both in 2006 and 2019, the highest average harmonic centralities (0.546 vs. 0.415), followed by British firms (0.301 vs 0.244) and German firms (0.279 vs. 0.217), all three countries showing decreasing mean index levels during the observation period (untabulated results). In all three countries, more industrial firms than financial firms form the respective top groups (table 5). Furthermore, only few companies manage to stay in the top five over time while banks become less central. Our findings on harmonic centralities corroborate the continuous decline of closeness within the national board director networks in parallel to a relative stability in terms of connected firms.

[Insert table 5 about here]

Betweenness centrality

Betweenness centrality measures the number of times a node lays on the shortest path between pairs of other nodes (Freeman 1977). Related to board interlocks, betweenness centrality allows to identify a network's "bridge companies" that, due to their position between numerous firms, may take control of flows of information and knowledge. The betweenness centrality of a firm is calculated by counting the number of times this firm is in the shortest path between any other pair of companies. A standardized score is calculated by dividing the previous result by the total number of firms minus one multiplied by that same number minus two, all divided by two.

Findings show highest average levels for British firms at the beginning of the period, a lead which further increases towards the end of the period. French firms are in second position, with rising scores between 2006 and

2019, whereas scores of German firms are noticeably lower in 2006 and drop to even lower levels in 2019 (untabulated results). The top five firms relative to their betweenness centrality is given in table 6. In all three countries, only few firms maintain their position in the top five group throughout time: in France, Accor, Bouygues, Engie, Eurazeo and Veolia; in Germany, Deutsche Lufthansa; and in the UK, a bank, Standard Chartered. Our results confirm an overall trend of declining board interlocks while the number of connected firms stays relatively stable.

[Insert table 6 about here]

4.3 Centralization analysis

While we have considered centrality so far at the firm level, it can also be quantified for an entire network through analysis which is referred to as centralization. Centralization analysis quantifies how central the most central actor of a network is when compared to the centrality of all other actors. To analyze this aspect for our three national samples, we compute the centralization score of Freeman (1978/79) which is obtained by dividing the sum in differences in centrality between the most central company and all other firms of the network by the total number of firms minus one multiplied by that same number minus two. The obtained centralization score may range from 0 (entirely dispersed network without any link between actors) to 1 (extremely centralized network).

[Insert table 7 about here]

At first glance (table 7), board director networks in our study do not seem very centralized which may be explained by the comparatively large size of the samples (a stronger centralization would have been observed by studying only Blue-Chip firms). That said, there are some significant differences between the three countries. At the beginning of the observation period, centralization in France is almost twice as high as in the UK but declined during the observation period, passing from 0.1676 in 2006 to 0.1096 in 2019 (-34.6%). Compared to France, the German network registered an even more remarkable diminution of its centralization, falling from 0.1918 in 2006 to 0.0859 fourteen years later (- 55.2%). Furthermore, Germany showed higher centralization levels between 2006 and 2015, and since 2016 Germany has fallen even further behind France. Germany's higher centralization in the first half of our study period seemingly results from more tightly connected firms in the core (see also figure 2) whose multiple ties have been sharply reduced over time. Centralization of the British network decreased over time at a similar pace as the French (0.0971 in 2006 vs.

0.0592 in 2019, -39.0%), yet starting at significantly lower absolute levels. In sum, centralization declined in all three countries with a higher rate in Germany, making the latter slip between a more centralized French and a less centralized British network. Given that most of the empirical studies presented in table 1 are only run over one year or do not estimate centralization, we are unable to compare our results with existing work.

4.4 Influence of regulation

Regulation related to board networks mostly regulate, directly or indirectly, individual ties within corporate networks. The scope of the restriction sensitively differs between France, Germany and the UK. French regulation appears to be the most restrictive of the three countries. In 2001, the NRE law[4] first limited the number of seats directors of French listed companies could hold to five. In 2015, the Macron law further reduced this limitation to three seats, with the asserted will being to avoid busy directors. In addition, the tightening of legal constraints regarding board composition (i.e., fixation of board female quotas by the Copé Zimmermann law in 2011 that targets 20% of each gender by 2014 and 40% by 2017; compulsory nomination, since 2013, of employee representatives in firms having more than 1,000 employees) may have also impacted the shape and density of board interlocks, leading companies to appoint fewer busy directors, since female directors and employee representatives do not belong to the traditional "old boys' clubs".

In contrast to rather strict rules in France, legislation appears softer in Germany, limiting since 1936 the number of simultaneous board mandates in national companies to a maximum of ten. On top of that, directors may hold additional board memberships in up to five subsidiaries, thereby bringing the maximum number of seats to fifteen, not including positions in foreign firms. In light of Germany's dual board structure, two companies are not allowed to mutually send executives to their supervisory boards. Since 2002, the German Code of Corporate Governance (Kodex) suggests to executives a maximum of five external board seats (thus limiting seats to ten when including mandates in subsidiaries), while no specific suggestion has been made for non-executive directors. Recommendations for executives have been further sharpened in 2010 (at maximum three external seats, limiting mandates to eight when including subsidiaries) and in 2019 (at maximum two external seats while explicitly advising against an external chairman position). In relation to directors without external executive functions, the code recommends since 2019 to not hold more than five external mandates, with Chairman positions counting for two mandates but makes no mention of mandates in subsidiaries. While the law continues to only concern national interlocks, public opinions have latterly converged to consider functions held in national and foreign companies.

[4] Loi relative aux nouvelles régulations économiques (NRE)

Concerning the UK, the Companies Act 2006 that consolidates all regulations applying to national firms, does not say anything about interlocks. The only limitation on multiple board seats can be found in the non-binding 2018 UK Corporate Governance Code following which an executive director should not hold more than one mandate in a FTSE 100 company. Reflecting the overall influence of the Cadbury Report (1992), the Code (and its modified versions) also advocates greater diversity and independence in the boardroom. This may further explain the observed trends of reduction in UK corporate networks over the period. That being said, guidelines by the London Stock Exchange (LSE) advise that candidates applying for independent director positions should have a proven experience in holding comparable positions in a similar-scale firm.[5] The absence of legally binding limitations on multiple board positions might also be explained by a comparatively lower relevance of corporate interlocks in the history of the country's economic system, particularly since the 1980s (Van Veen and Kratzer 2011; Buchnea et al. 2020). Finally, UK boards have been traditionally smaller in size than those of French and German companies (Ferreira and Kirchmaier 2013), which mechanically diminishes the opportunities to establish corporate links via board directors to the decision-making bodies of other companies.

To underline the impact of regulation on board interlocks, figure 4 depicts the evolution of the number of board ties per company of our three countries during the period (see also table 2) and highlights the years in which major laws and codes have been enacted. Concerning France, strengthened legislation on board composition and the number of board seats seemingly has a clear impact on the number of ties. New female directors have replaced directors with multiple positions as a consequence of the Copé Zimmermann law (2011) on gender balance in the boardroom. The Macron law (2015), lowering the limitation of the number of mandates from five to three, caused a second stage of tie cuts starting in 2015. Despite these cutbacks, the percentage of connected firms remains stable and is not affected by laws (figure 1), suggesting that national regulations have impacted the density of corporate networks at individual rather than corporate level.

Given the absence of major regulatory board reforms in Germany during our study period, the decrease in the number of board ties in 2009 can be seen as an anticipation of the recommendations of the 2010 version of the German Corporate Governance Code that suggests executives should not hold more than three external mandates. Furthermore, the financial crisis of the year 2008 may have contributed to tie cuts. That said, the accelerating pace of tie cuts in the last years of our observation period does not seem to be related to regulations, but rather to withdrawals of key actors, such as Allianz and Deutsche Bank, that have caused an overall thinning of the network.

[5] London Stock Exchange, Corporate Governance for Main Market and AIM Companies (White Page, 2012)

In light of the absence of legal reforms or strengthened restrictions with respect to board interlocks in the UK, the observed decrease of ties cannot be attributed to regulation but rather seems to be the continuation of internationalization trends initiated in the 1970s (Buchnea et al. 2020), or due to distinctive features of British capitalism whose dispersed ownership structures also led to a more fragmented network of control exerted by directors, in comparison to countries where interlocks reflect ownership structures more closely (Windolf and Beyer 1996). In addition to that, relationships among UK firms seem to be historically more founded on international competition in liberal markets rather than on coordination and control (Schnyder and Wilson 2014).

[Insert figure 4 about here]

4.5 Do cross-border networks supersede national networks?

As suggested by Carroll et al. (2010a, 2010b), changes in national board director networks can also be related to emerging transnational structures that may cause the erosion of national corporate connections. Such changes may be reactions to tightened national regulations and recommendations concerning board seat accumulation, leading, at the individual level, directors to look for more positions outside their home countries. At the corporate level, the ongoing internationalization of business relations may engender stronger needs for access to resources situated outside national borders. Alongside the analysis of national board interlocks, we have therefore also checked for the existence of a cross-border board director network that might have operated to compensate for the observed interlock declines at national levels.

Cross-border networks based on common directors have also undergone major changes during our 14-year observation period, but not in the sense of compensating the decrease of national interlocks (table 8). The number of transnationally connected actors decreases over time from 76 firms in 2006 to 50 in 2019 (-34.2%), thereby lowering their relative share from 30.4% in 2006 to 20% in 2019. While the number of cross-border connected German firms drastically dropped over the 14-year period (-53.8%), both toward France (-45.4%) and the UK (-70.0%), a comparatively lower proportion of French firms left the network (-32.3%) and the number of British companies remained even quite stable (-6.3%). The latter can be explained by an increase of ties with French firms (+18.2%) that overcompensates the sharp decline of links to German companies (-62.5%). All in all, French groups still represent almost half of the interconnected firms (44.7% in 2006 vs. 46.0% in 2019) while the proportion of German firms sinks (34.2% in 2006 vs. 24.0% in 2019) and the share of British companies rises (21.1% in 2006 vs. 30% in 2019). Unlike national networks, transnationally connected firms are not linked within one single

component, but links are scattered over several entities of which the biggest tend to get smaller over time (figures 5 and 6). In 2006, two-thirds (51) of the connected firms were linked in one large component, and this proportion reduces to around one quarter (13) in 2019. In parallel, the number of smaller separate entities at the periphery remains largely stable over time but comprises more firms (25 in 2006 and 37 in 2019). To sum up, our study cannot confirm the existence of a superseding effect of transnational board ties operating to substitute national interlocks.

[Insert figure 5 about here]

[Insert figure 6 about here]

[Insert table 8 about here]

A closer look at the sociometric parameters confirms the described decline of the cross-border network during the 14-year observation period (table 9). As the transnational network interconnects a diminishing proportion of the sample firms, the fraction of companies with a degree centrality of 0% increases during the observation period. Consequently, both the centralization and the density of the cross-border network sink during our observation period. For centralization, the highest level could be observed in 2007 (0.0380) and the weakest in 2014 (0.0184). Density was highest in 2009 (0.0012) and lowest in 2019 (0.0006). Accordingly, a very small number of companies showed a degree centrality of at minimum 2.5% (AstraZeneca and BNP Paribas in 2006 and 2007, Airbus from 2007 to 2011 and in 2015, Engie in 2016) with Airbus being the only company to reach the threshold of 2.5% in degree centrality when considered over the entire observation period; this is probably due to the European nature of its ownership structure since its inception which combines different national manufacturers.

[Insert table 9 about here]

When broken down to the firm level, low density and centralization in the network of cross-border board interlocks translate into a rather short list of companies that may be seen as comparatively central actors. Based on table 10 which lists all companies with a 14-year average degree centrality equal or superior to 1%, only six firms (three from France, two from Germany and one from the UK) stand out. The most central group is Airbus whose specific ownership structure including strong public shareholders from France, Germany, Spain, and the United Kingdom may drive its position in the network. Airbus shows an average degree centrality of 2.61% and

figures as the most central group in the cross-border sample throughout the entire fourteen-year observation period. Airbus is followed by Engie (France), Siemens (Germany), AstraZeneca (UK), AXA and Vivendi (France) that have all spent between seven and eleven years in the category of the ten most central firms sharing cross-border directors. While some financial groups such as BNP Paribas or Allianz have been key players in the cross-border network at the beginning of the observation period, they do not play important roles anymore in 2019 (Allianz backed out, BNP maintains one single connection). These aspects also confirm our national findings where banks appear to no longer feature as central actors in corporate board director networks (Carroll et al 2010b), this finding is contrary to older studies (Mizruchi and Stearns 1988; Yeo et al. 2003; Jonnergård et al. 2004). A similar trend can be observed for some large industrial groups such as Daimler (Germany), Sanofi (France) and Vodafone (UK). Even though a few firms such as Imerys (France) or Johnson Matthey (UK) have in parallel gained in importance, the overall network structure has been significantly thinned over time.

[Insert table 10 about here]

5 Discussion and conclusion

The purpose of this article was to analyze the structure and evolution of corporate networks based on shared board directors between the largest listed companies in three European countries: France, Germany, and the UK. Considering the period 2006 to 2019, we conducted an analysis of board ties from a corporate perspective focusing on firm connections through the presence of common directors rather than on the characteristics of such directors. We provided a current picture of the company networks based on directorship interlocks in the three countries and showed how these connections have evolved over the last fourteen years. While being exploratory and limited to a descriptive analysis, our study updates the existing literature on board interlocks in Europe.

Our study yields several contributions. First, our results showing the persistence of corporate networks confirm the advantage for firms to develop these networks, contributing to and corroborating the resource perspective according to which firms maintain ties to others to perpetuate their access to resources. Our findings on network structure echo Granovetter's (1973) concept of weak ties that considers sparse networks as being particularly effective to assure the flow of information and knowledge. The structure of corporate networks based on shared board directors has noticeably changed throughout time in all three considered countries, with significantly fewer board ties but a comparatively stable level of connected firms in the respective national samples (complete stability in France and slight declines in both Germany and the UK). Firms seem to avoid busy directors today, probably because they are aware of the arguments of

the agency theory: board members should have time enough for their monitoring role (Fich and Shivdasani 2006; Fattobene et al. 2018).

Second, our study suggests that regulatory changes contribute to explain the observed cutbacks of board ties over time in all three countries, without noticeably affecting the number of connected firms. While further statistical tests would be needed to evidence the influence of regulation, our findings are interesting for regulators in that they show that legal and best practice-related modifications which aim to reduce negative effects of multiple board seats do not prevent firms from maintaining connections through board director networks to access resources. From a theoretical point of view, the Law and Finance approach by La Porta et al. (1998), according to which networks may be more developed in French civil law countries, seems relevant to our study, explaining why French firms are the more connected. The distinction between different varieties of capitalism proposed by Hall and Soskice (2001) seems insufficient to explain the differences of evolution between France and Germany, both CMEs, which confirms the importance of further distinction with subtypes (Cárdenas 2012). In line with Cárdenas' findings for 2005, our study does not support the convergence of corporate networks structure across national models in 2019.

Third, in contrast to other previous empirical studies (Kentor and Jang 2004; Carroll et al. 2010b), our study shows a subsequent decrease of transnational interlocks throughout time, and therefore cannot confirm a substitution effect compensating the decline of domestic interlocking directorates with a multiplication of transnational board connections.

Our study design and results have the following shortcomings. First, sample sizes are quite limited, as we only selected companies based on their continuous listing in national stock market indices, during the entire observation period. As such, we have not retained those firms who disappeared following mergers, spin-offs or delisting. Second, a more detailed analysis of the connected firms with respect their standard industrial classification (SIC) could have been beneficial to further control for the resource argument of board director ties. Lastly, and related to this point, an analysis of the most central actors of the network with respect to the portfolio of industrial sectors that these firms are connected to through their busy board directors could have revealed more detailed results.

Further research on the evolution of corporate networks could focus on influence factors beyond regulation such as national business systems and the related varieties of capitalism (Van Veen and Kratzer 2011), differences in governance systems (Aguilera and Jackson 2003; Benton 2016), competition law rules on interlocking directorates (Thépot 2019), or institutional investors as providers of access to resources of other firms in which they are involved (Azar et al. 2018). Further research should also integrate macroeconomic shocks. For Italy, Romano and Favino (2013) suggest that the economic uncertainty following the financial crisis in 2008 pushed companies to multiply their connections to others through interlocking directorates. At first glance, figure 4 does not seem to confirm this argument as the number of ties

per connected company continues to decrease in France and Germany after 2008 and only temporarily rises in the UK. Instead, the financial crisis might also be seen as a catalyst of raising expectations for 'healthier' corporate governance practices, including the presence of fewer busy directors.

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Table 1 Overview of studies of national and transnational corporate networks based on shared directors in France, Germany and the United Kingdom

Country	Authors	Scope	Sample	Year/Period	Findings
France	Windolf and Nollert (2001)	Firms	374 firms	1995	Density: 0.004 (directed ties) and 0.016 (undirected ties); largest component comprises 51.1% (directed ties) / 52.9% (undirected ties) of all firms; proportion of isolated companies: 46.4% (directed ties) / 43.1% (undirected ties); centralization of directed ties: 0.064/0.029 (outdegree/indegree); centralization of undirected ties: 0.132; domination of financial groups.
	Chabi and Maati (2005, 2006)	Indiv. & firms	CAC40 firms	1996, 2000, 2004	95% of CAC40 firms share directors with other CAC40 firms (1996 and 2000); degree centrality: 0.103; closeness centrality: 0.080); financial groups are most central actors; one single component with small world characteristics
	Prinz (2011)	Indiv. & firms	CAC40 firms	2001-2005	Decline of ties but interconnectedness between firms remaining at high levels (one single component)
	Van Veen and Kratzer (2011)	Indiv. & firms	38 listed firms	2005	Second-highest density among 15 countries (0.240 for France); one single component
	Cárdenas (2012)	Firms	50 largest corporations	2005	Density 0.11; degree centralization 0.27. Cohesive networks.
	Buchwald (2014)	Firms	654 non-financial listed firms	2005 and 2011	Increase of the share of firms linked to other national companies (44.1% in 2011 vs. 42.5% in 2005)
	Ben Barka and Dardour (2015)	Firms	20 listed firms	2010	14 out of 20 firms connected to other sample firms; degree centrality: 0.137; closeness centrality: 0.091; betweenness centrality: 0.026
	Allemand and Brullebaut (2018)	Firms	30 CAC40 firms 88 SBF120 firms	2006-2015	100% of CAC40 are connected to other CAC40 firms in 2015; decrease of density (0.1678 in 2015 vs. 0.269 in 2006 for CAC40 firms and 0.0832 in 2015 vs. 0.1372 in 2006 for SBF120 firms) but stable degree centralities (respectively 0.0261 in 2015 vs. 0.0202 in 2006 and 0.0838 in 2015 vs. 0.0894 in 2006)
Germany	Windolf and Beyer (1996)	Firms	623 largest firms	1992	Important overlap of board ties with capital network; banks are most central actors; core component of banks and industrial groups
	Windolf and Nollert (2001)	Firms	300 firms 616 firms	1995	Share of connected firms for directed ties: 80.3% (N=300) / 79.5% (N=616); share of connected firms for undirected ties: 92.0% (N=300) / 90.6% (N=616); density of directed ties: 0.007 (N=300) / 0.003 (N=616); density of undirected ties: 0.036 (N=300) / 0.018 (N=616); centralization of directed ties: 0.172/0.020 (outdegree/indegree N=300) / 0.110/0.018 (outdegree/indegree N=616); centralization of undirected ties: 0.122 (N=300) / 0.101 (N=616); domination of financial groups; important overlaps of board ties with capital network
	Heinze (2004)	Firms	69 firms	1989 and 2001	Decrease of density of directed ties: 0.023 (2001) vs. 0.031 (1989); decrease of density of undirected ties: 0.112 (2001) vs. 0.128 (1989); quantitative decrease of ties but stable overall network structure (14.5% of isolated firms in the network of undirected ties for both years) with financial groups remaining at the core
	Prinz (2011)	Indiv.	DAX30 firms	2001-2005	Stability of ties and high interconnectedness between firms; one single component

		& firms			
	Van Veen and Kratzer (2011)	Indiv. & firms	30 listed firms	2005	Highest density among 15 countries (0.43); one single component
	Cárdenas (2012)	Firms	50 largest corporations	2005	Density 0.10; degree centralization 0.21. Cohesive networks.
	Andres et al. (2013)	Firms	133 listed firms	2003-2006	Strong core-periphery structure with dense and cohesive sub-groups
	Buchwald (2014)	Firms	695 non-financial listed firms	2005 and 2011	Decrease in proportion of firms linked to other companies (39% in 2011 vs. 46.5% in 2005)
United Kingdom	Windolf and Beyer (1996)	Firms	520 largest companies	1992	Almost no overlap of board ties with capital network; no dominance of the financial sector; no core component
	Windolf and Nollert (2001)	Firms	300 firms 520 firms	1995	Share of connected firms for directed ties: 61.3% (N=300) / 55.6% (N=520); share of connected firms for undirected ties: 68.0% (N=300) / 63.5% (N=520); density of directed ties: 0.003 (N=300) / 0.001 (N=520); density of undirected ties: 0.007 (N=300) / 0.004 (N=520); centralization of directed ties: 0.021/0.021 (outdegree/indegree N=300) / 0.014/0.012 (outdegree/indegree N=520); centralization of undirected ties: 0.03 (N=300) / 0.019 (N=520); almost no overlap of board ties with capital network
	Van Veen and Kratzer (2011)	Indiv.	29 listed firms	2005	Lowest density among 15 countries (0.04); one single weakly-tied component
	Cárdenas (2012)	Firms	50 largest corporations	2005	Density 0.03; degree centralization 0.10. Dispersed networks
	Buchwald (2014)	Firms	1852 non-financial listed firms	2005 and 2011	Decrease in proportion of firms linked to other companies (58.2% in 2011 vs. 61.4% in 2005)
	Homroy and Slechten (2019)	Firms	Around 350 listed firms	2006-2014	Increase in ties; stability of average degree (4.244 in 2014 vs. 4.224 in 2007), mean closeness (0.267 vs. 0.277) and mean betweenness (respectively 0.025 and 0.022)
	Buchnea et al. (2020)	Firms	50 financial and 200 non-financial firms	6 benchmark years between 1976 and 2010	Decline in ties over time; decline of average degree (3.94 in 2010 vs. 4.34 in 1976); financial institutions withdraw from network
Cross-border networks	Carroll and Fennema (2002)	Indiv. & firms	176 international firms in 12 countries (26 in UK, 52 in EU)	1976 and 1996	Increased proportion of cross-border interlocks (24.8% in 1996 vs. 22.8% in 1976); proportion in Europe: 16.3% (1996) and 13.9% (1976); 13% of sample firms with at least 3 transnational links; industrial firms dominate most central companies (respectively 77% in 1996 and 82% in 1976)

	Kentor and Jang (2004)	Firms	Fortune Global 500 firms	1983 and 1998	Increase of the share of transnational interlocks (19.8% in 1998 vs. 15.9% in 1983) within of an observed overall increase of (national and transnational) ties
	Carroll et al. (2010b)	Firms	European sub-sample based on the world's largest 100 financial and 400 non-financial firms	1996 and 2006	Increased proportion of transnational interlocks (32.7% in 2006 vs. 25.6% in 1996); increased share of boards with at least two transnational interlocks (40.9% in 2006 vs. 32.3% in 1996); central role of financial firms as "bridging" actors
	Van Veen and Kratzer (2011)	Indiv. & firms	362 firms (among which 38 French, 30 German, 29 UK firms)	2005	39% of interlocks are cross-border with a high proportion in UK (63%), more moderate levels in France (41%) and Germany (32%); France and Germany are most central countries within the transnational network
	Buchwald (2014)	Firms	17 European countries	2005 and 2011	Decrease of proportion of firms linked to other multinationals for Germany (14.4% in 2011 vs. 17.4% in 2005), but increase for France (19.0% in 2011 vs. 17.3% in 2005), UK (14.6% in 2011 vs. 10.9% in 2005) and whole sample (19% vs. 17.2%)
	Heemskerk and Takes (2016)	Firms	968.409 firms in 208 countries	2013	Cross-border interlocks represent 20% of all ties

Table 2 Descriptive statistics of national corporate networks based on shared directors*

			2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Δ 2019/ 2006
France: 82 firms	Number of ties	Σ	**318**	**312**	**317**	**318**	**301**	**276**	**273**	**277**	**252**	**231**	**195**	**186**	**175**	**178**	***-44.0%***
	as of simple tie	*Σ*	*270*	*256*	*262*	*267*	*261*	*245*	*242*	*247*	*227*	*211*	*181*	*174*	*163*	*168*	*-37.8%*
	as of multiple ties	*Σ*	*48*	*56*	*55*	*51*	*40*	*31*	*31*	*30*	*25*	*20*	*14*	*12*	*12*	*10*	*-79.2%*
	Interconnected firms	Σ	**75**	**75**	**75**	**76**	**78**	**78**	**75**	**76**	**77**	**77**	**76**	**76**	**75**	**75**	**+0.0%**
	in % of all firms	%	91.5	91.5	91.5	92.7	95.1	95.1	91.5	92.7	93.9	93.9	92.7	92.7	91.5	91.5	-
	Ties per connected firm	Σ	4.24	4.16	4.23	4.18	3.86	3.54	3.64	3.65	3.27	3.00	2.57	2.45	2.33	2.37	-44.1%
	Number of directors	Σ	**956**	**992**	**1,000**	**1,020**	**1,012**	**1,027**	**1,037**	**1,005**	**1,035**	**1,010**	**966**	**992**	**991**	**978**	**+2.3%**
	as of with multiple seats	*Σ*	*155*	*159*	*165*	*174*	*178*	*165*	*173*	*175*	*164*	*155*	*134*	*128*	*121*	*124*	*-20.0%*
		%	*10.6*	*16.0*	*16.5*	*17.1*	*17.6*	*16.1*	*16.7*	*17.4*	*15.8*	*15.3*	*13.9*	*12.9*	*12.2*	*12.7*	-
Germany: 85 firms	Number of ties*	Σ	**224**	**218**	**228**	**201**	**191**	**180**	**172**	**176**	**165**	**159**	**125**	**109**	**90**	**83**	***-62.9%***
	as of simple tie	*Σ*	*157*	*165*	*176*	*169*	*159*	*154*	*146*	*148*	*148*	*141*	*110*	*98*	*80*	*76*	*-51.6%*
	as of multiple ties	*Σ*	*67*	*53*	*52*	*32*	*32*	*26*	*26*	*28*	*16*	*18*	*15*	*11*	*10*	*7*	*-89.6%*
	Interconnected firms	Σ	**65**	**62**	**63**	**60**	**62**	**63**	**63**	**64**	**62**	**63**	**61**	**58**	**56**	**57**	**-12.3%**
	in % of all firms	%	76.5	72.9	74.1	70.6	72.9	74.1	74.1	75.3	72.9	74.1	71.8	68.2	65.9	67.1	-
	Ties per connected firm	Σ	3.45	3.52	3.62	3.35	3.08	2.86	2.73	2.75	2.66	2.52	2.05	1.88	1.61	1.46	-57.7%
	Number of directors	Σ	**1,427**	**1,449**	**1,503**	**1,438**	**1,399**	**1,396**	**1,430**	**1,481**	**1,430**	**1,448**	**1,338**	**1,362**	**1,367**	**1,374**	**-3.7%**
	as of with multiple seats	*Σ*	*130*	*125*	*130*	*121*	*114*	*115*	*106*	*109*	*103*	*99*	*80*	*78*	*72*	*71*	*-45.3%*
		%	*9.1%*	*8.6%*	*8.6%*	*8.4%*	*8.1%*	*8.2%*	*7.4%*	*7.4%*	*7.2%*	*6.8%*	*6.0%*	*5.7%*	*5.3%*	*5.2%*	-
UK: 83 firms	Number of ties	Σ	**134**	**125**	**131**	**135**	**121**	**117**	**113**	**115**	**122**	**116**	**97**	**93**	**96**	**94**	***-29.9%***
	as of simple tie	*Σ*	*129*	*121*	*127*	*130*	*117*	*113*	*108*	*113*	*120*	*116*	*96*	*92*	*95*	*93*	*-27.9%*
	as of multiple ties	*Σ*	*5*	*4*	*4*	*5*	*4*	*4*	*5*	*2*	*2*	*-*	*1*	*1*	*1*	*1*	*-80.0%*
	Interconnected firms	Σ	**74**	**72**	**71**	**67**	**71**	**75**	**74**	**75**	**74**	**76**	**73**	**73**	**69**	**68**	**-8.1%**
	in % of all firms	%	89.2	86.7	85.5	80.7	85.8	90.4	89.2	90.4	89.2	91.6	88.0	88.0	83.1	81.9	-
	Ties per connected firm	Σ	1.81	1.74	1.85	2.02	1.70	1.56	1.53	1.53	1.65	1.53	1.33	1.27	1.39	1.38	-23.8%
	Number of directors	Σ	**904**	**880**	**865**	**849**	**843**	**851**	**837**	**849**	**845**	**838**	**773**	**776**	**776**	**769**	**-14.9%**
	as of with multiple seats	*Σ*	*110*	*105*	*102*	*102*	*101*	*101*	*96*	*102*	*100*	*97*	*90*	*89*	*90*	*85*	*-22.7%*
		%	*12.2*	*11.9*	*11.8*	*12.0*	*12.0*	*11.9*	*11.5*	*12.0*	*11.8*	*11.6*	*11.6*	*11.5*	*11.6*	*11.1*	-

*Germany being characterized by a two-tier board system, numbers also comprise ties created by external board seats of members of the management board

Number of ties	Number of company pairs sharing at least one board member, whatever the number of board member in common; Example: we count one tie instead of two when company i shares at least one board member with company j
as of single tie	Number of company pairs with 1 director in common
as of double ties	Number of company pairs with 2 directors in common
as of triple ties	Number of company pairs with 3 directors in common
as of > 3x ties	Number of company pairs with more than 3 directors in common
Interconnected firms	Number of interconnected firms; a firm is interconnected if it shares at least one board member with another firm
Number of directors	Number of (different) directors in our sample
Directors with multiple seats	Number of (different) directors having more than one seat

Table 3 Density of national corporate networks based on shared directors

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Δ 2019/ 2006
France	0.048	0.047	0.048	0.048	0.045	0.042	0.041	0.042	0.038	0.035	0.029	0.028	0.026	0.027	-44.0%
Germany	0.031	0.031	0.032	0.028	0.027	0.025	0.024	0.025	0.023	0.022	0.018	0.015	0.013	0.012	-62.9%
UK	0.020	0.018	0.019	0.020	0.018	0.017	0.017	0.017	0.018	0.017	0.014	0.014	0.014	0.014	-29.9%

NB: analysis based on adjacency matrices

Table 4 Degree centralities of national corporate networks based on shared directors

			2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
France	Median	%	9.9	8.6	9.3	9.3	9.9	8.6	8.6	8.6	7.4	6.2	5.6	4.9	4.9	4.9
	Maximum	%	25.9	23.5	25.9	25.9	23.5	17.3	18.5	21.0	21.0	16.0	16.0	17.3	17.3	16.0
	Minimum	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Number of firms with a centrality degree of 0%	Σ	7	7	7	6	4	4	7	6	5	5	6	6	7	7
	Firms with a degree centrality ≥ 2.5%	%	84.1	85.4	81.7	79.3	80.5	81.7	79.3	81.7	78.0	79.3	75.6	73.2	72.0	72.0
	Firms with a degree centrality ≥ 5%	%	63.4	65.9	64.6	69.5	65.9	63.4	64.6	65.9	61.0	57.3	50.0	42.7	40.2	43.9
	Firms with a degree centrality ≥ 7.5%	%	53.7	53.7	57.3	58.5	57.3	53.7	51.2	51.2	43.9	40.2	25.6	25.6	19.5	23.2
	Firms with a degree centrality ≥ 10%	%	46.3	43.9	41.5	45.1	46.3	40.2	40.2	39.0	29.3	19.5	15.9	13.4	6.1	7.3
	Firms with a degree centrality ≥ 15%	%	22.0	18.3	15.9	17.1	11.0	7.3	4.9	6.1	6.1	2.4	1.2	1.2	1.2	1.2
	Firms with a degree centrality ≥ 20%	%	6.1	4.9	7.3	6.1	1.2	-	-	1.2	1.2	-	-	-	-	-
Germany	Median	%	3.6	3.6	3.6	3.6	3.6	3.6	2.4	3.6	2.4	2.4	1.2	1.2	1.2	1.2
	Maximum	%	25.0	22.6	23.8	21.4	20.2	17.9	19.0	17.9	17.9	16.7	13.1	13.1	11.9	10.7
	Minimum	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Number of firms with a degree centrality of 0%	Σ	20	23	22	25	23	22	22	21	23	22	24	27	29	28
	Firms with a degree centrality ≥ 2.5%	%	51.8	55.3	54.1	51.8	50.6	50.6	48.2	51.8	49.4	48.2	35.3	34.1	29.4	28.2
	Firms with a degree centrality ≥ 5%	%	37.6	41.2	43.5	42.4	40.0	38.8	37.6	37.6	34.1	34.1	29.4	25.9	16.5	12.9
	Firms with a degree centrality ≥ 7.5%	%	28.2	28.2	31.8	31.8	29.4	28.2	27.1	24.7	24.7	25.9	22.4	16.5	9.4	8.2
	Firms with a degree centrality ≥ 10%	%	23.5	25.9	25.9	23.5	23.5	20.0	17.6	17.6	18.8	15.3	10.6	4.7	3.5	1.2
	Firms with a degree centrality ≥ 15%	%	20.0	16.5	17.6	11.8	11.8	5.9	5.9	5.9	3.5	3.5	-	-	-	-
	Firms with a degree centrality ≥ 20%	%	8.2	4.7	4.7	1.2	1.2	-	-	-	-	-	-	-	-	-
United Kingdom	Median	%	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	2.4	2.4	2.4	2.4
	Maximum	%	13.4	12.2	9.8	11.0	9.8	8.5	8.5	7.3	11.0	9.8	7.3	8.5	8.5	8.5
	Minimum	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Number of firms with a degree centrality of 0%	Σ	9	11	12	16	12	8	9	8	9	7	10	10	14	15
	Firms with a degree centrality ≥ 2.5%	%	51.8	51.8	55.4	53.0	57.8	56.6	55.4	55.4	50.6	51.8	45.8	43.4	38.6	38.6
	Firms with a degree centrality ≥ 5.0%	%	27.7	26.5	28.9	33.7	22.9	18.1	16.9	13.3	20.5	20.5	8.4	3.6	12.0	12.0
	Firms with a degree centrality ≥ 7.5%	%	9.6	9.6	9.6	14.5	2.4	1.2	1.2	-	3.6	2.4	-	1.2	1.2	1.2
	Firms with a degree centrality ≥ 10%	%	4.8	1.2	-	1.2	-	-	-	-	1.2	-	-	-	-	-
	Firms with a degree centrality ≥ 15%	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Firms with a degree centrality ≥ 20%	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-

NB: analysis based on adjacency matrices

Table 5 Companies with highest harmonic centrality in national corporate networks

Year / country	Rank	2006	2010	2015	2019
France	**1**	Veolia (fka Vivendi Env.)	Engie	Engie	Veolia (fka Vivendi Env.)
	2	Accor	Total	Bouygues	Bouygues
	3	BNP Paribas	BNP Paribas	Veolia (fka Vivendi Env.)	Danone
	4	CNP Assurances	Vivendi	Eurazeo	Safran
	5	Lagardère	Sanofi	Total	Total
Germany	**1**	Allianz	Allianz	Siemens	Münchener Rückvers.
	2	Deutsche Lufthansa	Henkel	Linde	Siemens
	3	Deutsche Bank	Deutsche Lufthansa	Daimler	BMW
	4	E.ON	E.ON	Deutsche Lufthansa	Henkel
	5	Linde + RWE	BASF + ThyssenKrupp	Bayer + Mü. Rück	Daimler + Dt. Telekom
United Kingdom	**1**	Standard Chartered	Standard Chartered	Reckitt Benckiser Group	BP
	2	Vodafone	Vodafone	Standard Chartered	BAE Systems
	3	3i Group	Experian	Marks & Spencer Group	Sainsbury's
	4	Pearson	3i Group	British Land Company	Rolls-Royce Holdings
	5	Unilever	Diageo + National Grid	Inchcape + RELX + Intertek Group	Travis Perkins

NB: analysis based on adjacency matrices; fka = formerly known as

Table 6 Companies with highest betweenness centrality in national corporate networks

Year / country	Rank	2006	2010	2015	2019
France	**1**	Eurazeo	Engie	Eurazeo	Bouygues
	2	CNP Assurances	Accor	Bouygues	Orange
	3	Accor	Sanofi	L'Oréal	Safran
	4	Total	Crédit agricole	Engie	LVMH
	5	Lagardère	Kering (fka PPR)	Veolia (fka Vivendi Env.)	Veolia (fka Vivendi Env.)
Germany	**1**	Allianz	Allianz	Linde	Münchener Rückvers.
	2	BASF	Commerzbank	Siemens	Linde
	3	Henkel	K+S (fka Kali und Salz)	Deutsche Lufthansa	Deutsche Telekom
	4	Deutsche Lufthansa	Infineon Technologies	Bayer	Siemens
	5	Commerzbank	BASF	ProSiebenSat.1 Media	Deutsche Lufthansa
United Kingdom	**1**	Standard Chartered	National Grid	Reckitt Benckiser Group	NatWest Group
	2	Vodafone	Standard Chartered	Standard Chartered	BP
	3	HSBC Holdings	AstraZeneca	RELX	Sainsbury's
	4	Pearson	Experian	BT Group	BAE Systems
	5	3i Group	3i Group	Marks & Spencer Group	Rolls-Royce Holdings

NB: analysis based on adjacency matrices; fka = formerly known as

Table 7 Centralization of national corporate networks based on shared directors

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
France	0.1676	0.1441	0.1679	0.1676	0.1475	0.0920	0.1056	0.1296	0.1373	0.0932	0.1043	0.1198	0.1231	0.1096
Germany	0.1918	0.1691	0.1784	0.1618	0.1525	0.1312	0.1457	0.1324	0.1355	0.1251	0.0983	0.1028	0.0961	0.0859
UK	0.0971	0.0873	0.0605	0.0718	0.0635	0.0522	0.0534	0.0403	0.0757	0.0650	0.0458	0.0595	0.0586	0.0592

NB: analysis based on adjacency matrices

Table 8 Descriptive statistics of the cross-national corporate network based on shared directors

		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Δ 2019/ 2006
Cross-national ties	**Σ**	**69**	**76**	**75**	**77**	**60**	**58**	**53**	**54**	**56**	**54**	**49**	**46**	**42**	***38***	***-44.9%***
France-Germany	*Σ*	*36*	*41*	*35*	*33*	*24*	*26*	*27*	*27*	*25*	*29*	*21*	*22*	*21*	*18*	*-50.0%*
France-UK	*Σ*	*23*	*27*	*29*	*30*	*29*	*25*	*20*	*19*	*24*	*18*	*20*	*16*	*18*	*17*	*-26.1%*
Germany-UK	*Σ*	*10*	*8*	*11*	*14*	*7*	*7*	*6*	*8*	*7*	*7*	*8*	*8*	*3*	*3*	*-70.0%*
as of simple ties	***Σ***	***67***	***75***	***74***	***76***	***57***	***56***	***51***	***49***	***54***	***52***	***47***	***45***	***41***	***37***	***-44.8%***
France-Germany	*Σ*	*34*	*40*	*34*	*32*	*22*	*24*	*25*	*23*	*23*	*27*	*19*	*22*	*20*	*17*	*-50.0%*
France-UK	*Σ*	*23*	*27*	*29*	*30*	*28*	*25*	*20*	*18*	*24*	*18*	*20*	*15*	*18*	*17*	*-26.1%*
Germany-UK	*Σ*	*10*	*8*	*11*	*14*	*7*	*7*	*6*	*8*	*7*	*7*	*8*	*8*	*3*	*3*	*-70.0%*
as of multiple ties	***Σ***	***2***	***1***	***1***	***1***	***3***	***2***	***2***	***5***	***2***	***2***	***2***	***1***	***1***	***1***	***-50.0%***
France-Germany	*Σ*	*2*	*1*	*1*	*1*	*2*	*2*	*2*	*4*	*2*	*2*	*2*	*-*	*1*	*1*	*-50.0%*
France-UK	*Σ*	*-*	*-*	*-*	*-*	*1*	*-*	*-*	*1*	*-*	*-*	*-*	*1*	*-*	*-*	*-*
Germany-UK	*Σ*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*
Interconnected firms	**Σ**	**76**	**81**	**78**	**79**	**70**	**70**	**64**	**68**	**71**	**68**	**64**	**61**	**58**	**50**	**-34.2%**
	%	*30.4*	*32.4*	*31.2*	*31.6*	*28.0*	*28.0*	*25.6*	*27.2*	*28.4*	*27.2*	*25.6*	*24.4*	*23.2*	*20.0*	*-*
as of French	***Σ***	***34***	***37***	***35***	***36***	***33***	***30***	***27***	***26***	***28***	***27***	***24***	***20***	***23***	***23***	***-32.3%***
	%	*44.7*	*45.7*	*44.9*	*45.6*	*47.1*	*42.9*	*42.2*	*38.2*	*39.4*	*39.7*	*37.5*	*32.8*	*39.7*	*46.0*	*-*
connected to German	*Σ*	*20*	*24*	*20*	*21*	*17*	*19*	*18*	*16*	*16*	*19*	*14*	*14*	*14*	*12*	*-40.0%*
connected to UK	*Σ*	*19*	*22*	*24*	*26*	*27*	*22*	*17*	*16*	*19*	*15*	*14*	*11*	*14*	*13*	*-31.6%*
as of German	***Σ***	***26***	***24***	***20***	***21***	***15***	***18***	***19***	***21***	***21***	***22***	***19***	***21***	***18***	***12***	***-53.8%***
	%	*34.2*	*29.6*	*25.6*	*26.6*	*21.4*	*25.7*	*29.7*	*30.9*	*29.6*	*32.4*	*29.7*	*34.4*	*31.0*	*24.0*	*-*
connected to French	*Σ*	*22*	*22*	*18*	*18*	*14*	*17*	*17*	*17*	*18*	*19*	*15*	*16*	*15*	*12*	*-45.4%*
connected to UK	*Σ*	*10*	*7*	*9*	*10*	*6*	*5*	*6*	*7*	*5*	*5*	*6*	*7*	*3*	*3*	*-70.0%*
as of British	*Σ*	***16***	***20***	***23***	***22***	***22***	***22***	***18***	***21***	***22***	***19***	***21***	***20***	***17***	***15***	***-6.3%***
	%	*21.1*	*24.7*	*29.5*	*27.8*	*31.4*	*31.4*	*28.1*	*30.9*	*31.0*	*27.9*	*32.8*	*32.8*	*29.3*	*30.0*	*-*
connected to French	*Σ*	*11*	*16*	*18*	*16*	*17*	*18*	*14*	*15*	*18*	*14*	*14*	*13*	*14*	*13*	*+18.2%*
connected to German	*Σ*	*8*	*6*	*7*	*8*	*5*	*5*	*4*	*7*	*7*	*7*	*7*	*7*	*3*	*3*	*-62.5%*
Cross-national board directors	**Σ**	**43**	**41**	**46**	**45**	**40**	**40**	**39**	**40**	**38**	**37**	**35**	**34**	**33**	**29**	**-32.6%**

Number of cross-national ties	Number of company pairs located in two different countries and sharing at least one board member, whatever the number of board member in common; example: we count one tie instead of two when the company i shares at least one board member with the company j
Number of cross-national directors	Number of directors holding one or more board positions in each of at least two countries of the sample

Table 9 Degree centralities and centralization of the cross-national corporate network based on shared directors

		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Median	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maximum	%	3.2	4.0	3.6	3.6	2.8	2.8	2.4	2.4	2.0	2.8	2.8	2.4	2.0	2.0
Minimum	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Firms with a degree centrality of 0%	Σ	174	169	172	171	180	180	186	182	179	182	186	189	192	200
	%	69.6	67.6	68.8	68.4	72.0	72.0	74.4	72.8	71.6	72.8	74.4	75.6	76.8	80.0
Firms with a degree centrality ≥ 2.5%	Σ	2	3	1	1	1	1	-	-	-	1	1	-	-	-
	%	0.8	1.2	0.4	0.4	0.4	0.4	-	-	-	0.4	0.4	-	-	-
Centralization	-	0.0302	0.0380	0.0340	0.0339	0.0264	0.0265	0.0226	0.0225	0.0184	0.0266	0.0268	0.0228	0.0189	0.0190
Density	-	0.0011	0.0012	0.0012	0.0012	0.0010	0.0009	0.0009	0.0009	0.0009	0.0009	0.0008	0.0007	0.0007	0.0006

NB: analysis based on adjacency matrices

Table 10 Companies with an average degree centrality ≥1% in the cross-national corporate network

Company	**Country**	**Average degree centrality** (in %)	**Number of years in the top 10**
Airbus (fka EADS)	Germany	2.61	14
Engie	France	1.32	7
Siemens	Germany	1.26	11
AstraZeneca	United Kingdom	1.00	7
AXA	France	1.00	7
Vivendi	France	1.00	11

NB: analysis based on adjacency matrices; fka = formerly known as

Figure 1 Percentage of interconnected firms per country

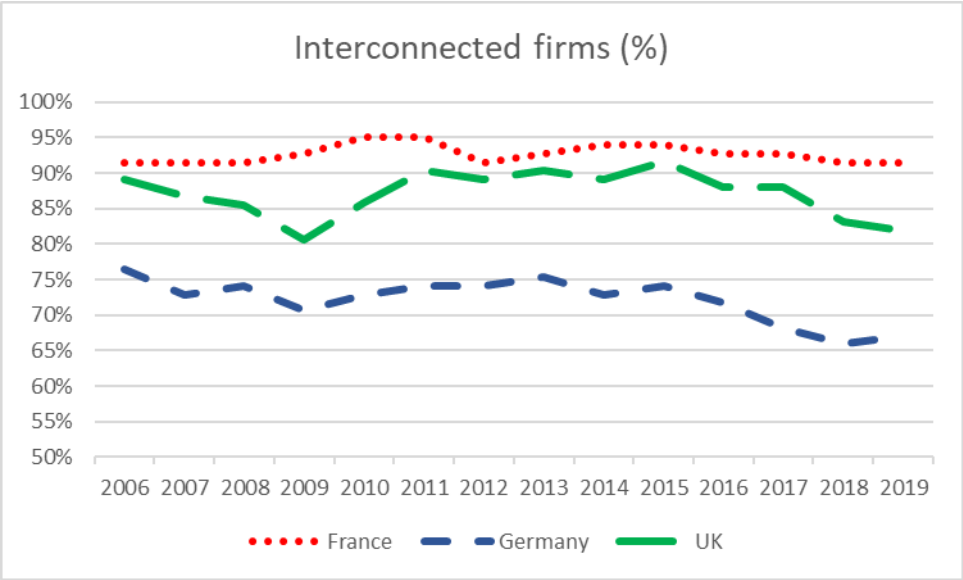
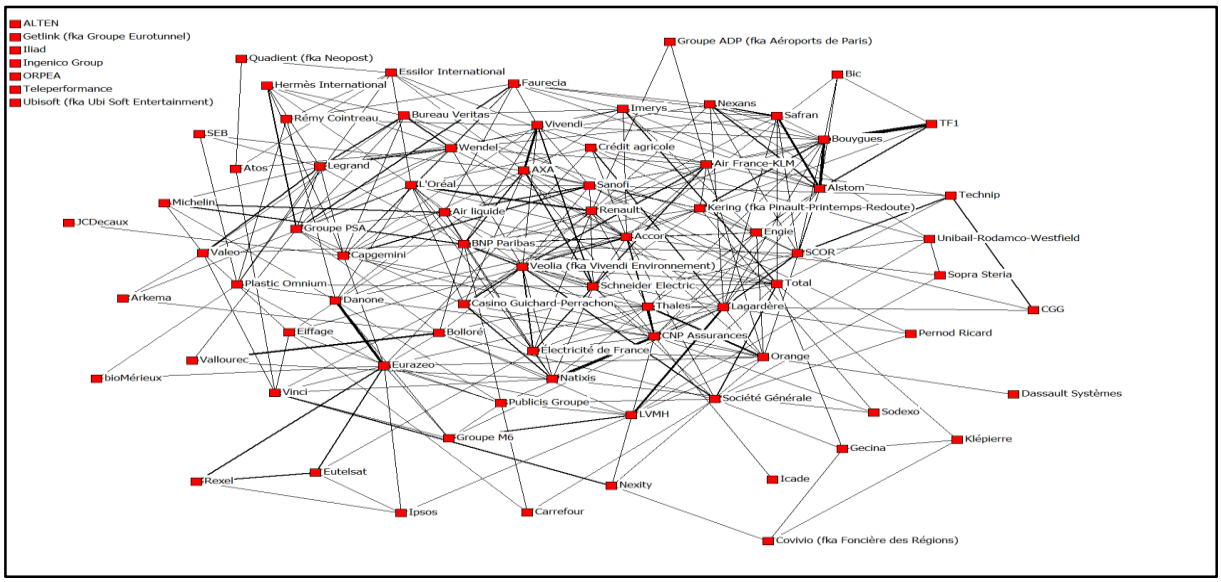
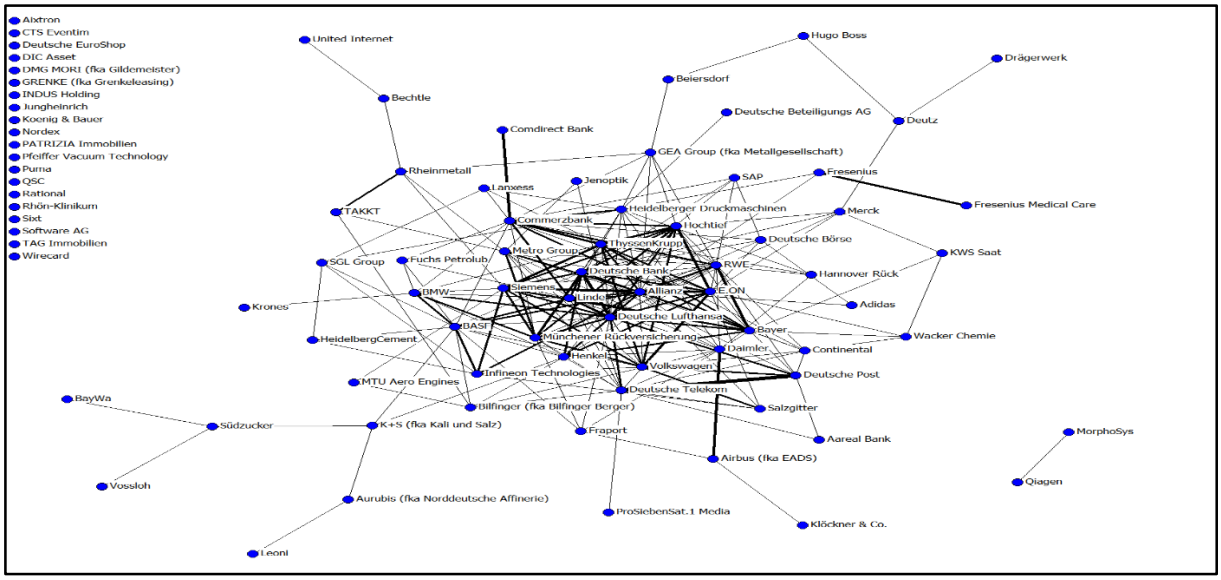
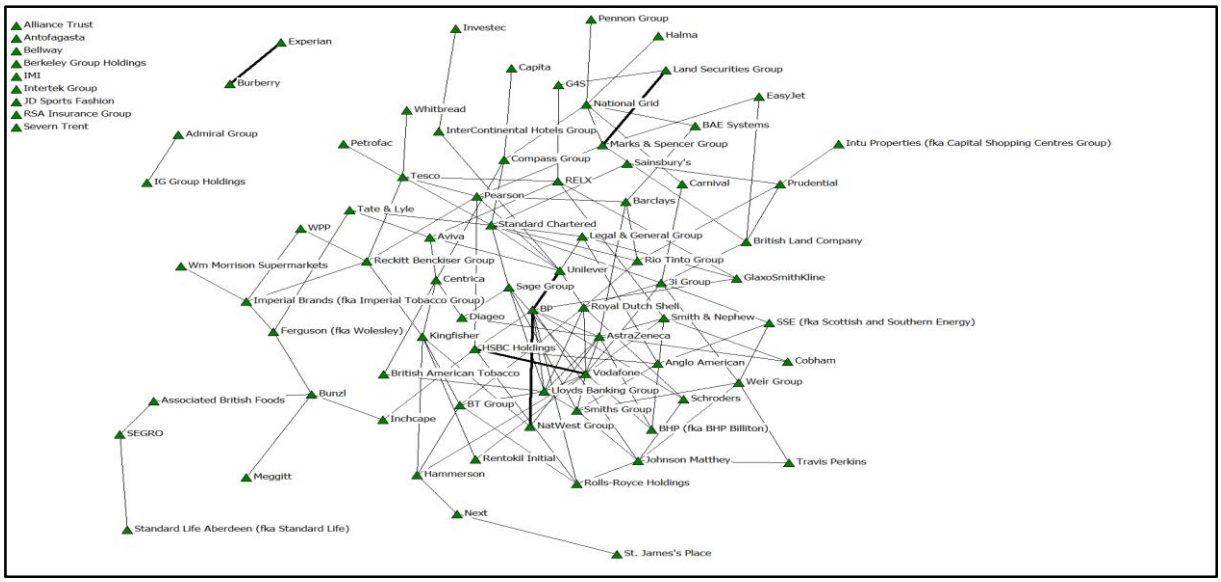


Figure 2 Board interlocks in France, Germany and the United Kingdom in 2006

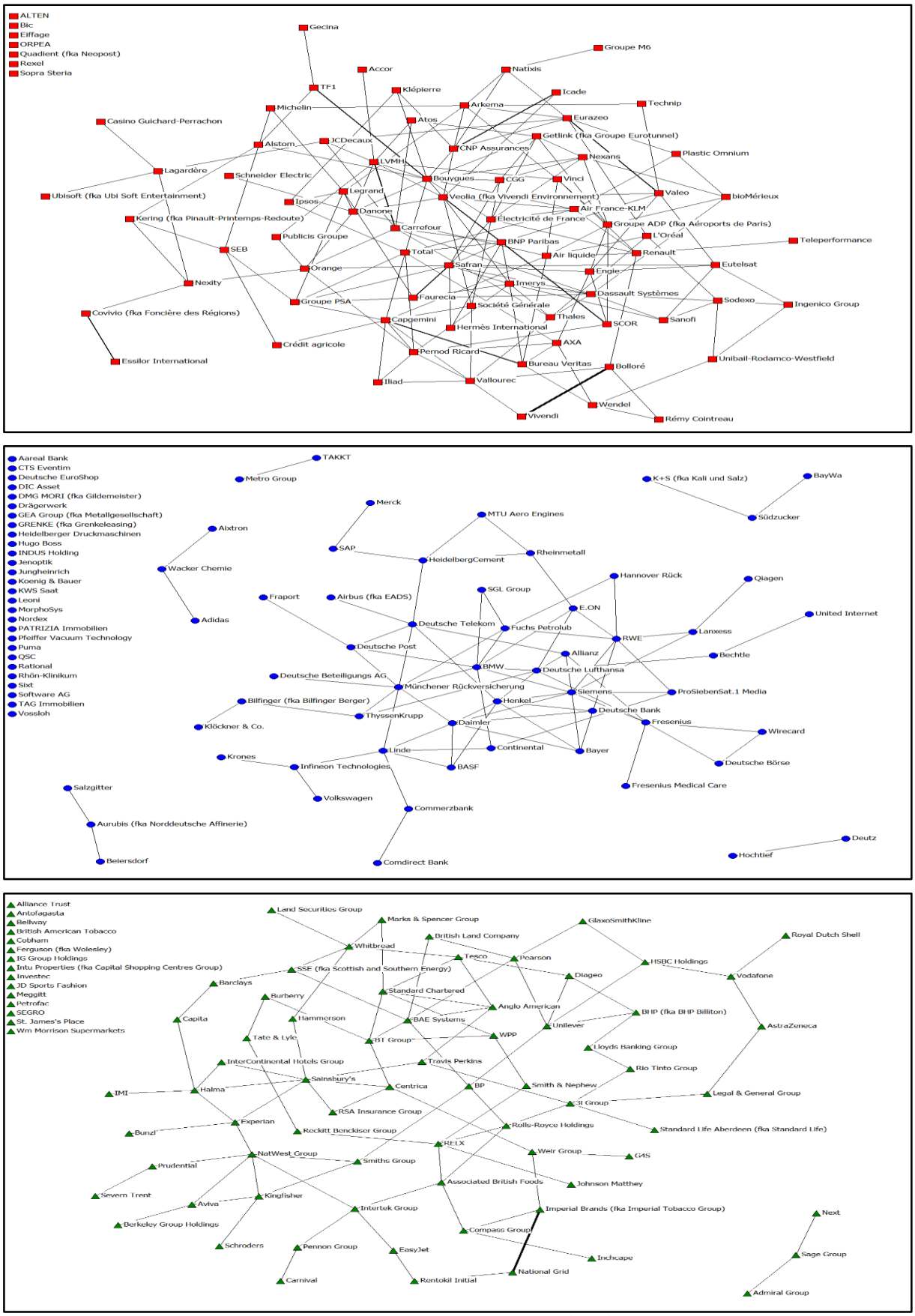






NB: board ties based on weighted matrices; tie strength represents connection intensity; fka = formerly known as

Figure 3 Board interlocks in France, Germany and the United Kingdom in 2019



NB: board ties based on weighted matrices; tie strength represents connection intensity; fka = formerly known as

Figure 4 Evolution of the number of ties per connected firm

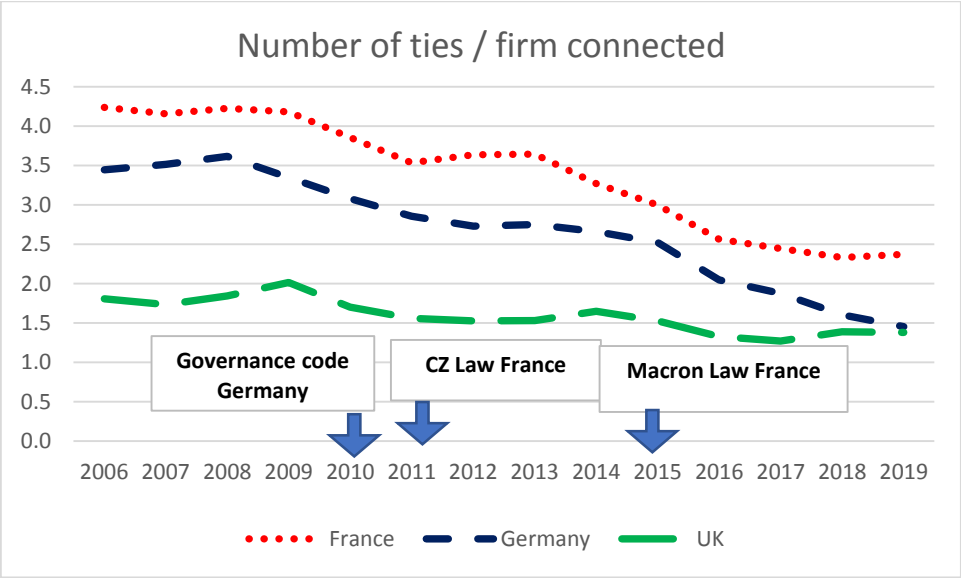
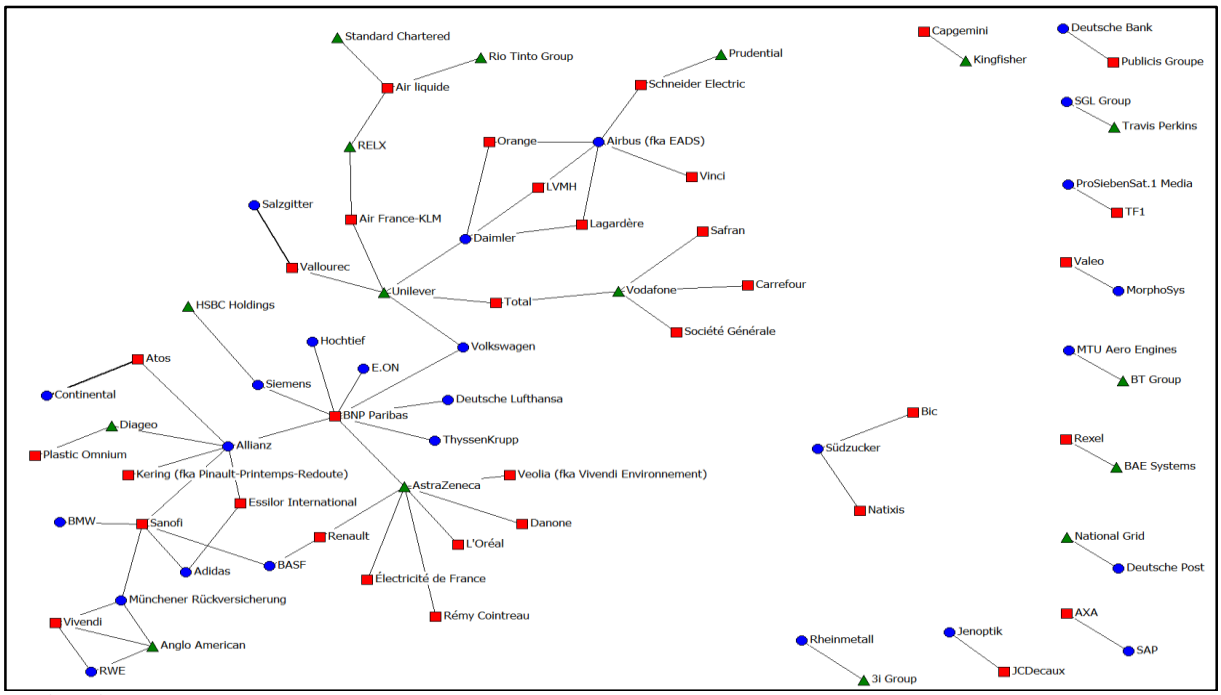
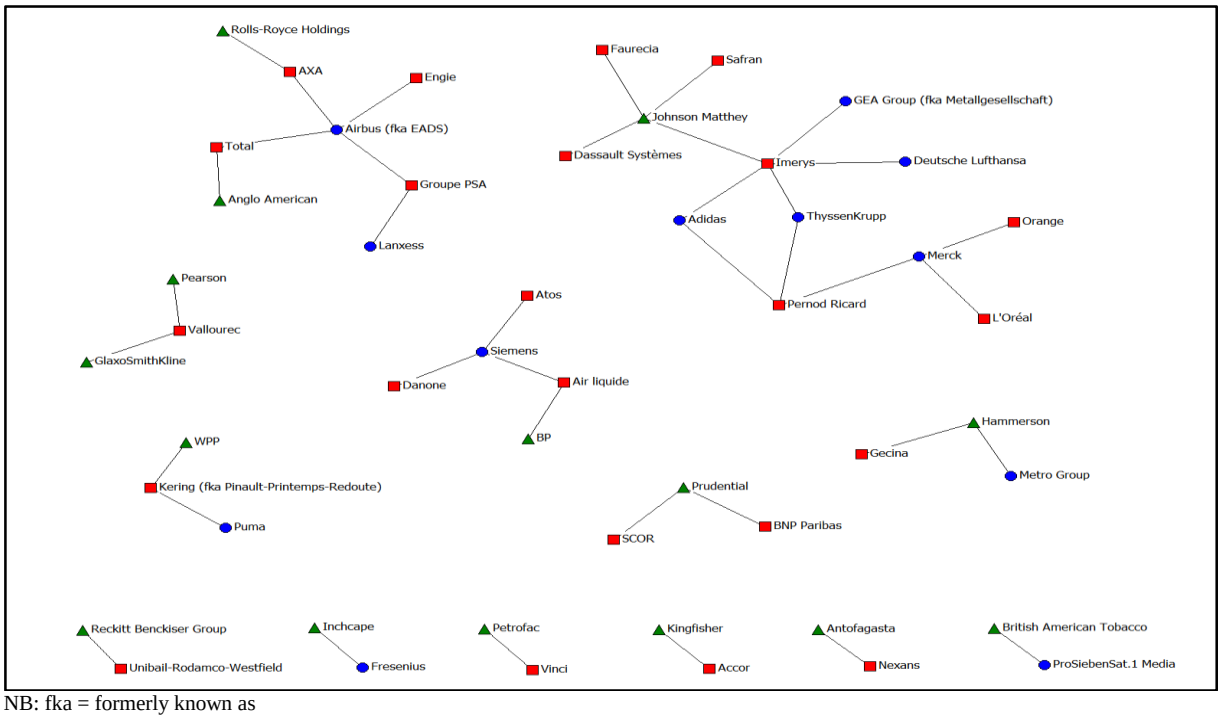


Figure 5 Transnational board interlocks between France, Germany and the United Kingdom in 2006



NB: fka = formerly known as

Figure 6 Transnational board interlocks between France, Germany and the United Kingdom in 2019



NB: fka = formerly known as

Table 1

Table 1 Overview of studies of national and transnational corporate networks based on shared directors in France, Germany and the United Kingdom

Country	Authors	Scope	Sample	Year/Period	Findings
France	Windolf and Nollert (2001)	Firms	374 firms	1995	Density: 0.004 (directed ties) and 0.016 (undirected ties); largest component comprises 51.1% (directed ties) / 52.9% (undirected ties) of all firms; proportion of isolated companies: 46.4% (directed ties) / 43.1% (undirected ties); centralization of directed ties: 0.064/0.029 (outdegree/indegree); centralization of undirected ties: 0.132; domination of financial groups.
	Chabi and Maati (2005, 2006)	Indiv. & firms	CAC40 firms	1996, 2000, 2004	95% of CAC40 firms share directors with other CAC40 firms (1996 and 2000); degree centrality: 0.103; closeness centrality: 0.080); financial groups are most central actors; one single component with small world characteristics
	Prinz (2011)	Indiv. & firms	CAC40 firms	2001-2005	Decline of ties but interconnectedness between firms remaining at high levels (one single component)
	Van Veen and Kratzer (2011)	Indiv. & firms	38 listed firms	2005	Second-highest density among 15 countries (0.240 for France); one single component
	Cárdenas (2012)	Firms	50 largest corporations	2005	Density 0.11; degree centralization 0.27. Cohesive networks.
	Buchwald (2014)	Firms	654 non-financial listed firms	2005 and 2011	Increase of the share of firms linked to other national companies (44.1% in 2011 vs. 42.5% in 2005)
	Ben Barka and Dardour (2015)	Firms	20 listed firms	2010	14 out of 20 firms connected to other sample firms; degree centrality: 0.137; closeness centrality: 0.091; betweenness centrality: 0.026
	Allemand and Brullebaut (2018)	Firms	30 CAC40 firms 88 SBF120 firms	2006-2015	100% of CAC40 are connected to other CAC40 firms in 2015; decrease of density (0.1678 in 2015 vs. 0.269 in 2006 for CAC40 firms and 0.0832 in 2015 vs. 0.1372 in 2006 for SBF120 firms) but stable degree centralities (respectively 0.0261 in 2015 vs. 0.0202 in 2006 and 0.0838 in 2015 vs. 0.0894 in 2006)
Germany	Windolf and Beyer (1996)	Firms	623 largest firms	1992	Important overlap of board ties with capital network; banks are most central actors; core component of banks and industrial groups
	Windolf and Nollert (2001)	Firms	300 firms 616 firms	1995	Share of connected firms for directed ties: 80.3% (N=300) / 79.5% (N=616); share of connected firms for undirected ties: 92.0% (N=300) / 90.6% (N=616); density of directed ties: 0.007 (N=300) / 0.003 (N=616); density of undirected ties: 0.036 (N=300) / 0.018 (N=616); centralization of directed ties: 0.172/0.020 (outdegree/indegree N=300) / 0.110/0.018 (outdegree/indegree N=616); centralization of undirected ties: 0.122 (N=300) / 0.101 (N=616); domination of financial groups; important overlaps of board ties with capital network
	Heinze (2004)	Firms	69 firms	1989 and 2001	Decrease of density of directed ties: 0.023 (2001) vs. 0.031 (1989); decrease of density of undirected ties: 0.112 (2001) vs. 0.128 (1989); quantitative decrease of ties but stable overall network structure (14.5% of isolated firms in the network of undirected ties for both years) with financial groups remaining at the core
	Prinz (2011)	Indiv.	DAX30 firms	2001-2005	Stability of ties and high interconnectedness between firms; one single component

		& firms			
	Van Veen and Kratzer (2011)	Indiv. & firms	30 listed firms	2005	Highest density among 15 countries (0.43); one single component
	Cárdenas (2012)	Firms	50 largest corporations	2005	Density 0.10; degree centralization 0.21. Cohesive networks.
	Andres et al. (2013)	Firms	133 listed firms	2003-2006	Strong core-periphery structure with dense and cohesive sub-groups
	Buchwald (2014)	Firms	695 non-financial listed firms	2005 and 2011	Decrease in proportion of firms linked to other companies (39% in 2011 vs. 46.5% in 2005)
United Kingdom	Windolf and Beyer (1996)	Firms	520 largest companies	1992	Almost no overlap of board ties with capital network; no dominance of the financial sector; no core component
	Windolf and Nollert (2001)	Firms	300 firms 520 firms	1995	Share of connected firms for directed ties: 61.3% (N=300) / 55.6% (N=520); share of connected firms for undirected ties: 68.0% (N=300) / 63.5% (N=520); density of directed ties: 0.003 (N=300) / 0.001 (N=520); density of undirected ties: 0.007 (N=300) / 0.004 (N=520); centralization of directed ties: 0.021/0.021 (outdegree/indegree N=300) / 0.014/0.012 (outdegree/indegree N=520); centralization of undirected ties: 0.03 (N=300) / 0.019 (N=520); almost no overlap of board ties with capital network
	Van Veen and Kratzer (2011)	Indiv.	29 listed firms	2005	Lowest density among 15 countries (0.04); one single weakly-tied component
	Cárdenas (2012)	Firms	50 largest corporations	2005	Density 0.03; degree centralization 0.10. Dispersed networks
	Buchwald (2014)	Firms	1852 non-financial listed firms	2005 and 2011	Decrease in proportion of firms linked to other companies (58.2% in 2011 vs. 61.4% in 2005)
	Homroy and Slechten (2019)	Firms	Around 350 listed firms	2006-2014	Increase in ties; stability of average degree (4.244 in 2014 vs. 4.224 in 2007), mean closeness (0.267 vs. 0.277) and mean betweenness (respectively 0.025 and 0.022)
	Buchnea et al. (2020)	Firms	50 financial and 200 non-financial firms	6 benchmark years between 1976 and 2010	Decline in ties over time; decline of average degree (3.94 in 2010 vs. 4.34 in 1976); financial institutions withdraw from network
Cross-border networks	Carroll and Fennema (2002)	Indiv. & firms	176 international firms in 12 countries (26 in UK, 52 in EU)	1976 and 1996	Increased proportion of cross-border interlocks (24.8% in 1996 vs. 22.8% in 1976); proportion in Europe: 16.3% (1996) and 13.9% (1976); 13% of sample firms with at least 3 transnational links; industrial firms dominate most central companies (respectively 77% in 1996 and 82% in 1976)

	Kentor and Jang (2004)	Firms	Fortune Global 500 firms	1983 and 1998	Increase of the share of transnational interlocks (19.8% in 1998 vs. 15.9% in 1983) within of an observed overall increase of (national and transnational) ties
	Carroll et al. (2010b)	Firms	European sub-sample based on the world's largest 100 financial and 400 non-financial firms	1996 and 2006	Increased proportion of transnational interlocks (32.7% in 2006 vs. 25.6% in 1996); increased share of boards with at least two transnational interlocks (40.9% in 2006 vs. 32.3% in 1996); central role of financial firms as "bridging" actors
	Van Veen and Kratzer (2011)	Indiv. & firms	362 firms (among which 38 French, 30 German, 29 UK firms)	2005	39% of interlocks are cross-border with a high proportion in UK (63%), more moderate levels in France (41%) and Germany (32%); France and Germany are most central countries within the transnational network
	Buchwald (2014)	Firms	17 European countries	2005 and 2011	Decrease of proportion of firms linked to other multinationals for Germany (14.4% in 2011 vs. 17.4% in 2005), but increase for France (19.0% in 2011 vs. 17.3% in 2005), UK (14.6% in 2011 vs. 10.9% in 2005) and whole sample (19% vs. 17.2%)
	Heemskerk and Takes (2016)	Firms	968.409 firms in 208 countries	2013	Cross-border interlocks represent 20% of all ties

Table 2

Table 2 Descriptive statistics of national corporate networks based on shared directors*

			2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Δ 2019/ 2006
France: 82 firms	Number of ties	Σ	**318**	**312**	**317**	**318**	**301**	**276**	**273**	**277**	**252**	**231**	**195**	**186**	**175**	**178**	***-44.0%***
	as of simple tie	*Σ*	*270*	*256*	*262*	*267*	*261*	*245*	*242*	*247*	*227*	*211*	*181*	*174*	*163*	*168*	*-37.8%*
	as of multiple ties	*Σ*	*48*	*56*	*55*	*51*	*40*	*31*	*31*	*30*	*25*	*20*	*14*	*12*	*12*	*10*	*-79.2%*
	Interconnected firms	Σ	**75**	**75**	**75**	**76**	**78**	**78**	**75**	**76**	**77**	**77**	**76**	**76**	**75**	**75**	**+0.0%**
	in % of all firms	%	91.5	91.5	91.5	92.7	95.1	95.1	91.5	92.7	93.9	93.9	92.7	92.7	91.5	91.5	-
	Ties per connected firm	Σ	4.24	4.16	4.23	4.18	3.86	3.54	3.64	3.65	3.27	3.00	2.57	2.45	2.33	2.37	-44.1%
	Number of directors	Σ	**956**	**992**	**1,000**	**1,020**	**1,012**	**1,027**	**1,037**	**1,005**	**1,035**	**1,010**	**966**	**992**	**991**	**978**	**+2.3%**
	as of with multiple seats	*Σ*	*155*	*159*	*165*	*174*	*178*	*165*	*173*	*175*	*164*	*155*	*134*	*128*	*121*	*124*	*-20.0%*
		%	*10.6*	*16.0*	*16.5*	*17.1*	*17.6*	*16.1*	*16.7*	*17.4*	*15.8*	*15.3*	*13.9*	*12.9*	*12.2*	*12.7*	-
Germany: 85 firms	Number of ties*	Σ	**224**	**218**	**228**	**201**	**191**	**180**	**172**	**176**	**165**	**159**	**125**	**109**	**90**	**83**	***-62.9%***
	as of simple tie	*Σ*	*157*	*165*	*176*	*169*	*159*	*154*	*146*	*148*	*148*	*141*	*110*	*98*	*80*	*76*	*-51.6%*
	as of multiple ties	*Σ*	*67*	*53*	*52*	*32*	*32*	*26*	*26*	*28*	*16*	*18*	*15*	*11*	*10*	*7*	*-89.6%*
	Interconnected firms	Σ	**65**	**62**	**63**	**60**	**62**	**63**	**63**	**64**	**62**	**63**	**61**	**58**	**56**	**57**	**-12.3%**
	in % of all firms	%	76.5	72.9	74.1	70.6	72.9	74.1	74.1	75.3	72.9	74.1	71.8	68.2	65.9	67.1	-
	Ties per connected firm	Σ	3.45	3.52	3.62	3.35	3.08	2.86	2.73	2.75	2.66	2.52	2.05	1.88	1.61	1.46	-57.7%
	Number of directors	Σ	**1,427**	**1,449**	**1,503**	**1,438**	**1,399**	**1,396**	**1,430**	**1,481**	**1,430**	**1,448**	**1,338**	**1,362**	**1,367**	**1,374**	**-3.7%**
	as of with multiple seats	*Σ*	*130*	*125*	*130*	*121*	*114*	*115*	*106*	*109*	*103*	*99*	*80*	*78*	*72*	*71*	*-45.3%*
		%	*9.1%*	*8.6%*	*8.6%*	*8.4%*	*8.1%*	*8.2%*	*7.4%*	*7.4%*	*7.2%*	*6.8%*	*6.0%*	*5.7%*	*5.3%*	*5.2%*	-
UK: 83 firms	Number of ties	Σ	**134**	**125**	**131**	**135**	**121**	**117**	**113**	**115**	**122**	**116**	**97**	**93**	**96**	**94**	***-29.9%***
	as of simple tie	*Σ*	*129*	*121*	*127*	*130*	*117*	*113*	*108*	*113*	*120*	*116*	*96*	*92*	*95*	*93*	*-27.9%*
	as of multiple ties	*Σ*	*5*	*4*	*4*	*5*	*4*	*4*	*5*	*2*	*2*	*-*	*1*	*1*	*1*	*1*	*-80.0%*
	Interconnected firms	Σ	**74**	**72**	**71**	**67**	**71**	**75**	**74**	**75**	**74**	**76**	**73**	**73**	**69**	**68**	**-8.1%**
	in % of all firms	%	89.2	86.7	85.5	80.7	85.8	90.4	89.2	90.4	89.2	91.6	88.0	88.0	83.1	81.9	-
	Ties per connected firm	Σ	1.81	1.74	1.85	2.02	1.70	1.56	1.53	1.53	1.65	1.53	1.33	1.27	1.39	1.38	-23.8%
	Number of directors	Σ	**904**	**880**	**865**	**849**	**843**	**851**	**837**	**849**	**845**	**838**	**773**	**776**	**776**	**769**	**-14.9%**
	as of with multiple seats	*Σ*	*110*	*105*	*102*	*102*	*101*	*101*	*96*	*102*	*100*	*97*	*90*	*89*	*90*	*85*	*-22.7%*
		%	*12.2*	*11.9*	*11.8*	*12.0*	*12.0*	*11.9*	*11.5*	*12.0*	*11.8*	*11.6*	*11.6*	*11.5*	*11.6*	*11.1*	-

*Germany being characterized by a two-tier board system, numbers also comprise ties created by external board seats of members of the management board

Number of ties	Number of company pairs sharing at least one board member, whatever the number of board member in common; Example: we count one tie instead of two when company i shares at least one board member with company j
as of single tie	Number of company pairs with 1 director in common
as of double ties	Number of company pairs with 2 directors in common
as of triple ties	Number of company pairs with 3 directors in common
as of > 3x ties	Number of company pairs with more than 3 directors in common
Interconnected firms	Number of interconnected firms; a firm is interconnected if it shares at least one board member with another firm
Number of directors	Number of (different) directors in our sample
Directors with multiple seats	Number of (different) directors having more than one seat

Figure 1

Figure 1 Percentage of interconnected firms per country

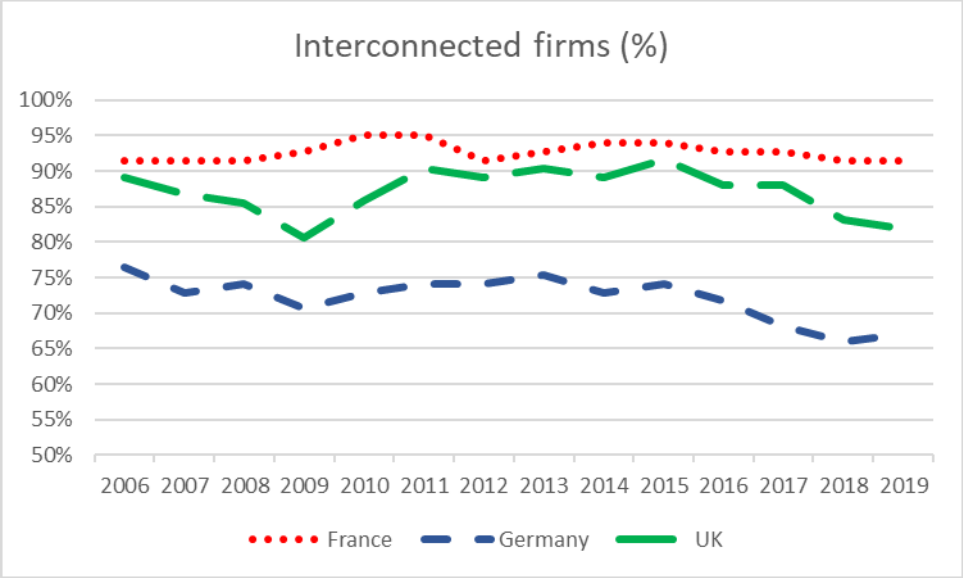
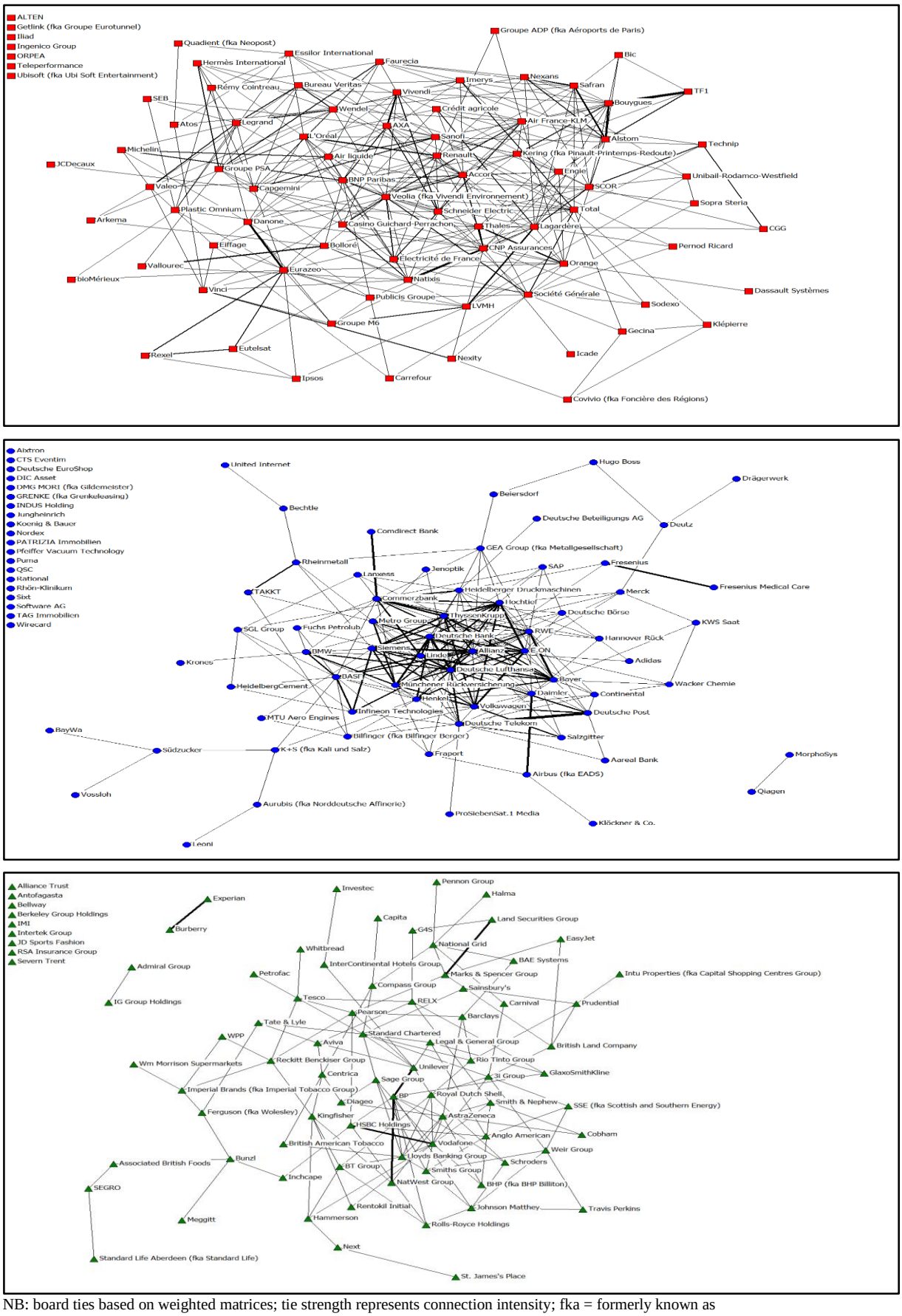


Figure 2

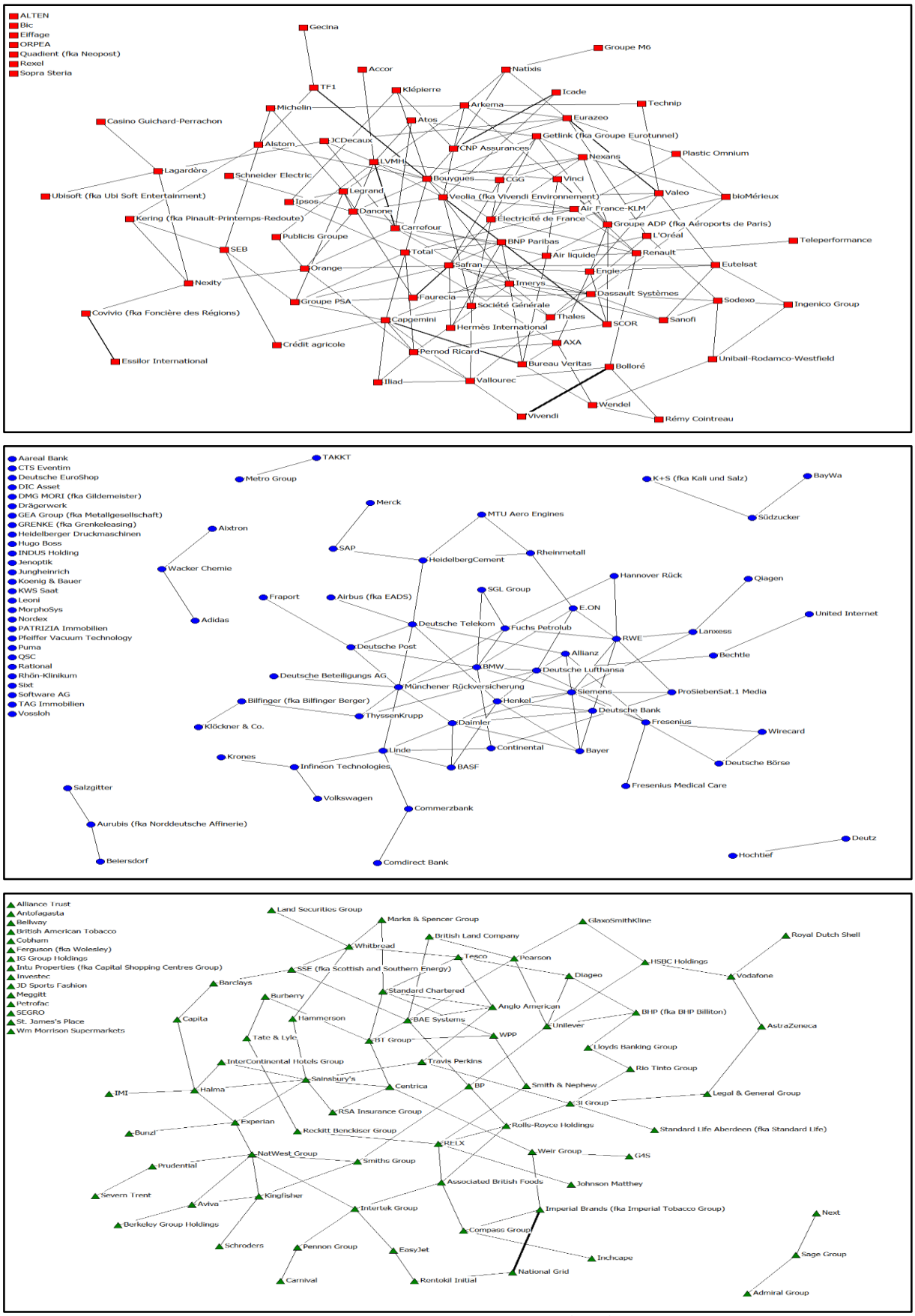
Figure 2 Board interlocks in France, Germany and the United Kingdom in 2006



NB: board ties based on weighted matrices; tie strength represents connection intensity; fka = formerly known as

Figure 3

Figure 3 Board interlocks in France, Germany and the United Kingdom in 2019



NB: board ties based on weighted matrices; tie strength represents connection intensity; fka = formerly known as

Table 3 Density of national corporate networks based on shared directors

	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Δ 2019/ 2006**
France	0.048	0.047	0.048	0.048	0.045	0.042	0.041	0.042	0.038	0.035	0.029	0.028	0.026	0.027	-44.0%
Germany	0.031	0.031	0.032	0.028	0.027	0.025	0.024	0.025	0.023	0.022	0.018	0.015	0.013	0.012	-62.9%
UK	0.020	0.018	0.019	0.020	0.018	0.017	0.017	0.017	0.018	0.017	0.014	0.014	0.014	0.014	-29.9%

NB: analysis based on adjacency matrices

Table 4

Table 4 Degree centralities of national corporate networks based on shared directors

			2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
France	Median	%	9.9	8.6	9.3	9.3	9.9	8.6	8.6	8.6	7.4	6.2	5.6	4.9	4.9	4.9
	Maximum	%	25.9	23.5	25.9	25.9	23.5	17.3	18.5	21.0	21.0	16.0	16.0	17.3	17.3	16.0
	Minimum	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Number of firms with a centrality degree of 0%	Σ	7	7	7	6	4	4	7	6	5	5	6	6	7	7
	Firms with a degree centrality ≥ 2.5%	%	84.1	85.4	81.7	79.3	80.5	81.7	79.3	81.7	78.0	79.3	75.6	73.2	72.0	72.0
	Firms with a degree centrality ≥ 5%	%	63.4	65.9	64.6	69.5	65.9	63.4	64.6	65.9	61.0	57.3	50.0	42.7	40.2	43.9
	Firms with a degree centrality ≥ 7.5%	%	53.7	53.7	57.3	58.5	57.3	53.7	51.2	51.2	43.9	40.2	25.6	25.6	19.5	23.2
	Firms with a degree centrality ≥ 10%	%	46.3	43.9	41.5	45.1	46.3	40.2	40.2	39.0	29.3	19.5	15.9	13.4	6.1	7.3
	Firms with a degree centrality ≥ 15%	%	22.0	18.3	15.9	17.1	11.0	7.3	4.9	6.1	6.1	2.4	1.2	1.2	1.2	1.2
	Firms with a degree centrality ≥ 20%	%	6.1	4.9	7.3	6.1	1.2	-	-	1.2	1.2	-	-	-	-	-
Germany	Median	%	3.6	3.6	3.6	3.6	3.6	3.6	2.4	3.6	2.4	2.4	1.2	1.2	1.2	1.2
	Maximum	%	25.0	22.6	23.8	21.4	20.2	17.9	19.0	17.9	17.9	16.7	13.1	13.1	11.9	10.7
	Minimum	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Number of firms with a degree centrality of 0%	Σ	20	23	22	25	23	22	22	21	23	22	24	27	29	28
	Firms with a degree centrality ≥ 2.5%	%	51.8	55.3	54.1	51.8	50.6	50.6	48.2	51.8	49.4	48.2	35.3	34.1	29.4	28.2
	Firms with a degree centrality ≥ 5%	%	37.6	41.2	43.5	42.4	40.0	38.8	37.6	37.6	34.1	34.1	29.4	25.9	16.5	12.9
	Firms with a degree centrality ≥ 7.5%	%	28.2	28.2	31.8	31.8	29.4	28.2	27.1	24.7	24.7	25.9	22.4	16.5	9.4	8.2
	Firms with a degree centrality ≥ 10%	%	23.5	25.9	25.9	23.5	23.5	20.0	17.6	17.6	18.8	15.3	10.6	4.7	3.5	1.2
	Firms with a degree centrality ≥ 15%	%	20.0	16.5	17.6	11.8	11.8	5.9	5.9	5.9	3.5	3.5	-	-	-	-
	Firms with a degree centrality ≥ 20%	%	8.2	4.7	4.7	1.2	1.2	-	-	-	-	-	-	-	-	-
United Kingdom	Median	%	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	2.4	2.4	2.4	2.4
	Maximum	%	13.4	12.2	9.8	11.0	9.8	8.5	8.5	7.3	11.0	9.8	7.3	8.5	8.5	8.5
	Minimum	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Number of firms with a degree centrality of 0%	Σ	9	11	12	16	12	8	9	8	9	7	10	10	14	15
	Firms with a degree centrality ≥ 2.5%	%	51.8	51.8	55.4	53.0	57.8	56.6	55.4	55.4	50.6	51.8	45.8	43.4	38.6	38.6
	Firms with a degree centrality ≥ 5.0%	%	27.7	26.5	28.9	33.7	22.9	18.1	16.9	13.3	20.5	20.5	8.4	3.6	12.0	12.0
	Firms with a degree centrality ≥ 7.5%	%	9.6	9.6	9.6	14.5	2.4	1.2	1.2	-	3.6	2.4	-	1.2	1.2	1.2
	Firms with a degree centrality ≥ 10%	%	4.8	1.2	-	1.2	-	-	-	-	1.2	-	-	-	-	-
	Firms with a degree centrality ≥ 15%	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Firms with a degree centrality ≥ 20%	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-

NB: analysis based on adjacency matrices

Table 5

Table 5 Companies with highest harmonic centrality in national corporate networks

Year / country	Rank	2006	2010	2015	2019
France	**1**	Veolia (fka Vivendi Env.)	Engie	Engie	Veolia (fka Vivendi Env.)
	2	Accor	Total	Bouygues	Bouygues
	3	BNP Paribas	BNP Paribas	Veolia (fka Vivendi Env.)	Danone
	4	CNP Assurances	Vivendi	Eurazeo	Safran
	5	Lagardère	Sanofi	Total	Total
Germany	**1**	Allianz	Allianz	Siemens	Münchener Rückvers.
	2	Deutsche Lufthansa	Henkel	Linde	Siemens
	3	Deutsche Bank	Deutsche Lufthansa	Daimler	BMW
	4	E.ON	E.ON	Deutsche Lufthansa	Henkel
	5	Linde + RWE	BASF + ThyssenKrupp	Bayer + Mü. Rück	Daimler + Dt. Telekom
United Kingdom	**1**	Standard Chartered	Standard Chartered	Reckitt Benckiser Group	BP
	2	Vodafone	Vodafone	Standard Chartered	BAE Systems
	3	3i Group	Experian	Marks & Spencer Group	Sainsbury's
	4	Pearson	3i Group	British Land Company	Rolls-Royce Holdings
	5	Unilever	Diageo + National Grid	Inchcape + RELX + Intertek Group	Travis Perkins

NB: analysis based on adjacency matrices; fka = formerly known as

Table 6 Companies with highest betweenness centrality in national corporate networks

Year / country	Rank	2006	2010	2015	2019
France	**1**	Eurazeo	Engie	Eurazeo	Bouygues
	2	CNP Assurances	Accor	Bouygues	Orange
	3	Accor	Sanofi	L'Oréal	Safran
	4	Total	Crédit agricole	Engie	LVMH
	5	Lagardère	Kering (fka PPR)	Veolia (fka Vivendi Env.)	Veolia (fka Vivendi Env.)
Germany	**1**	Allianz	Allianz	Linde	Münchener Rückvers.
	2	BASF	Commerzbank	Siemens	Linde
	3	Henkel	K+S (fka Kali und Salz)	Deutsche Lufthansa	Deutsche Telekom
	4	Deutsche Lufthansa	Infineon Technologies	Bayer	Siemens
	5	Commerzbank	BASF	ProSiebenSat.1 Media	Deutsche Lufthansa
United Kingdom	**1**	Standard Chartered	National Grid	Reckitt Benckiser Group	NatWest Group
	2	Vodafone	Standard Chartered	Standard Chartered	BP
	3	HSBC Holdings	AstraZeneca	RELX	Sainsbury's
	4	Pearson	Experian	BT Group	BAE Systems
	5	3i Group	3i Group	Marks & Spencer Group	Rolls-Royce Holdings

NB: analysis based on adjacency matrices; fka = formerly known as

Table 7 Centralization of national corporate networks based on shared directors

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
France	0.1676	0.1441	0.1679	0.1676	0.1475	0.0920	0.1056	0.1296	0.1373	0.0932	0.1043	0.1198	0.1231	0.1096
Germany	0.1918	0.1691	0.1784	0.1618	0.1525	0.1312	0.1457	0.1324	0.1355	0.1251	0.0983	0.1028	0.0961	0.0859
UK	0.0971	0.0873	0.0605	0.0718	0.0635	0.0522	0.0534	0.0403	0.0757	0.0650	0.0458	0.0595	0.0586	0.0592

NB: analysis based on adjacency matrice

Figure 4

Figure 4 Evolution of the number of ties per connected firm

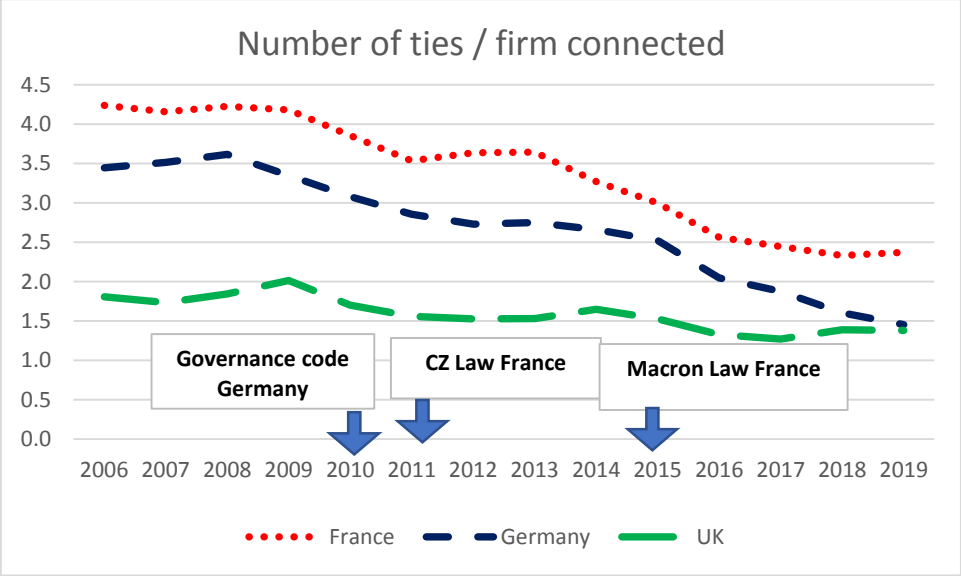
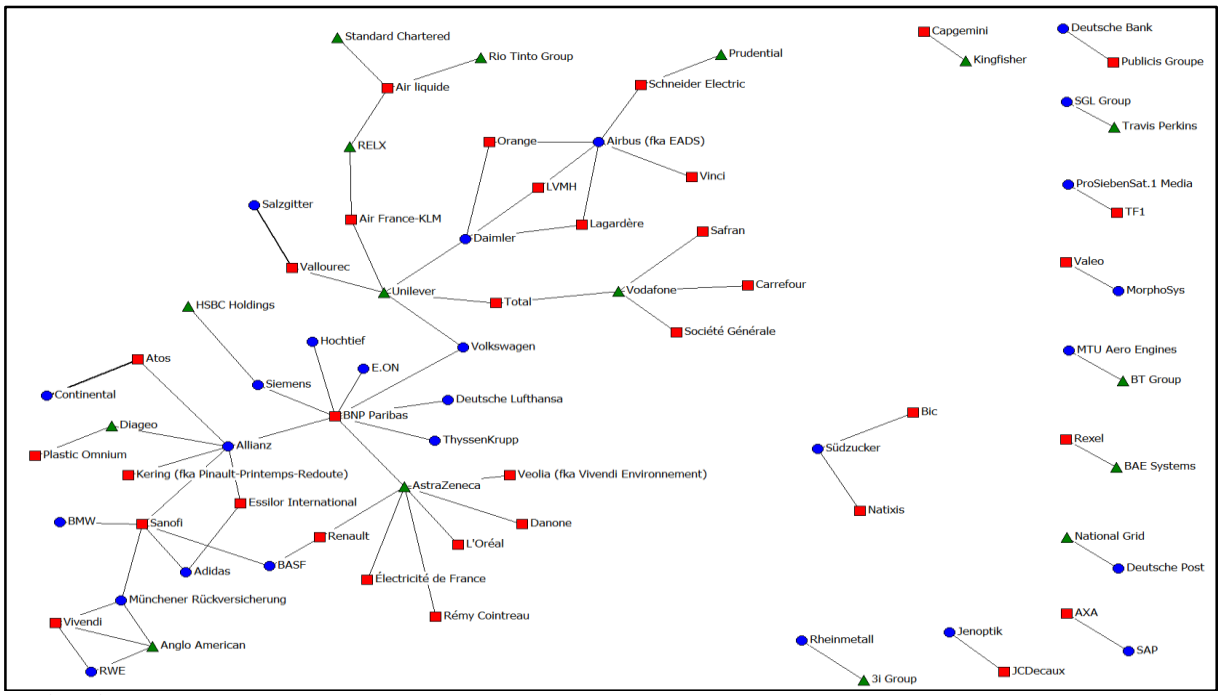


Figure 5

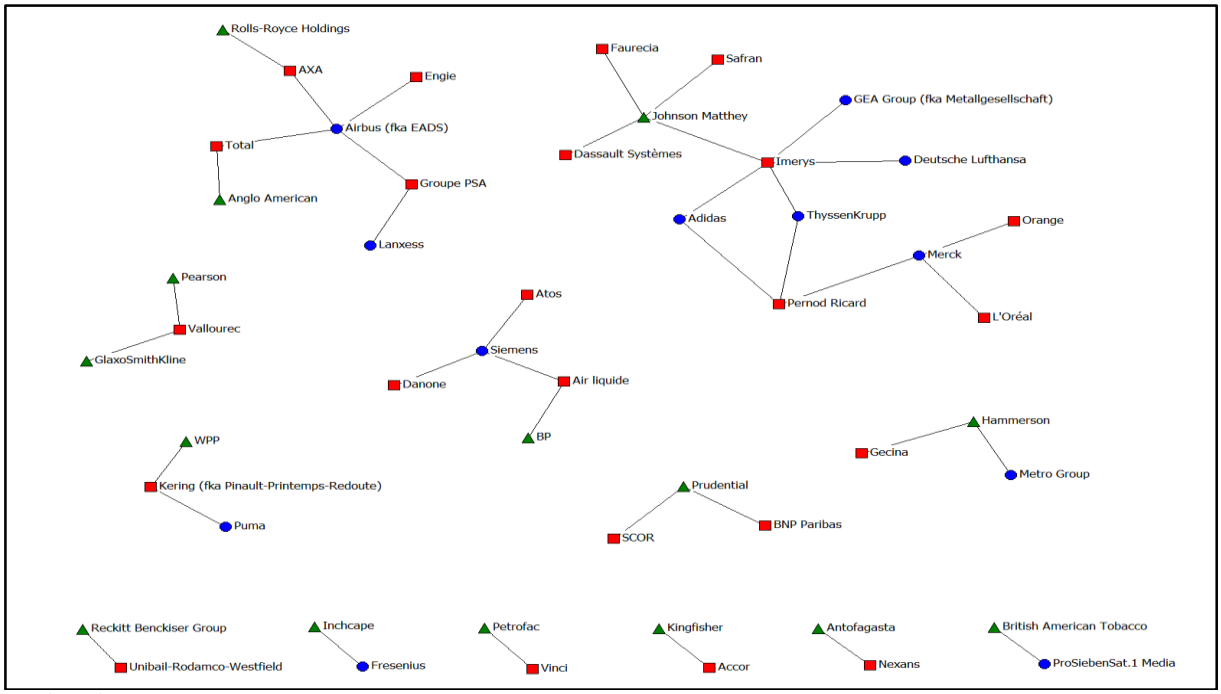
Figure 5 Transnational board interlocks between France, Germany and the United Kingdom in 2006



NB: fka = formerly known as

Figure 6

Figure 6 Transnational board interlocks between France, Germany and the United Kingdom in 2019



NB: fka = formerly known as

Table 8

Table 8 Descriptive statistics of the cross-national corporate network based on shared directors

		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Δ 2019/ 2006
Cross-national ties	**Σ**	**69**	**76**	**75**	**77**	**60**	**58**	**53**	**54**	**56**	**54**	**49**	**46**	**42**	***38***	***-44.9%***
France-Germany	*Σ*	*36*	*41*	*35*	*33*	*24*	*26*	*27*	*27*	*25*	*29*	*21*	*22*	*21*	*18*	*-50.0%*
France-UK	*Σ*	*23*	*27*	*29*	*30*	*29*	*25*	*20*	*19*	*24*	*18*	*20*	*16*	*18*	*17*	*-26.1%*
Germany-UK	*Σ*	*10*	*8*	*11*	*14*	*7*	*7*	*6*	*8*	*7*	*7*	*8*	*8*	*3*	*3*	*-70.0%*
as of simple ties	***Σ***	***67***	***75***	***74***	***76***	***57***	***56***	***51***	***49***	***54***	***52***	***47***	***45***	***41***	***37***	***-44.8%***
France-Germany	*Σ*	*34*	*40*	*34*	*32*	*22*	*24*	*25*	*23*	*23*	*27*	*19*	*22*	*20*	*17*	*-50.0%*
France-UK	*Σ*	*23*	*27*	*29*	*30*	*28*	*25*	*20*	*18*	*24*	*18*	*20*	*15*	*18*	*17*	*-26.1%*
Germany-UK	*Σ*	*10*	*8*	*11*	*14*	*7*	*7*	*6*	*8*	*7*	*7*	*8*	*8*	*3*	*3*	*-70.0%*
as of multiple ties	***Σ***	***2***	***1***	***1***	***1***	***3***	***2***	***2***	***5***	***2***	***2***	***2***	***1***	***1***	***1***	***-50.0%***
France-Germany	*Σ*	*2*	*1*	*1*	*1*	*2*	*2*	*2*	*4*	*2*	*2*	*2*	*-*	*1*	*1*	*-50.0%*
France-UK	*Σ*	*-*	*-*	*-*	*-*	*1*	*-*	*-*	*1*	*-*	*-*	*-*	*1*	*-*	*-*	*-*
Germany-UK	*Σ*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*	*-*
Interconnected firms	**Σ**	**76**	**81**	**78**	**79**	**70**	**70**	**64**	**68**	**71**	**68**	**64**	**61**	**58**	**50**	**-34.2%**
	%	*30.4*	*32.4*	*31.2*	*31.6*	*28.0*	*28.0*	*25.6*	*27.2*	*28.4*	*27.2*	*25.6*	*24.4*	*23.2*	*20.0*	*-*
as of French	***Σ***	***34***	***37***	***35***	***36***	***33***	***30***	***27***	***26***	***28***	***27***	***24***	***20***	***23***	***23***	***-32.3%***
	%	*44.7*	*45.7*	*44.9*	*45.6*	*47.1*	*42.9*	*42.2*	*38.2*	*39.4*	*39.7*	*37.5*	*32.8*	*39.7*	*46.0*	*-*
connected to German	*Σ*	*20*	*24*	*20*	*21*	*17*	*19*	*18*	*16*	*16*	*19*	*14*	*14*	*14*	*12*	*-40.0%*
connected to UK	*Σ*	*19*	*22*	*24*	*26*	*27*	*22*	*17*	*16*	*19*	*15*	*14*	*11*	*14*	*13*	*-31.6%*
as of German	***Σ***	***26***	***24***	***20***	***21***	***15***	***18***	***19***	***21***	***21***	***22***	***19***	***21***	***18***	***12***	***-53.8%***
	%	*34.2*	*29.6*	*25.6*	*26.6*	*21.4*	*25.7*	*29.7*	*30.9*	*29.6*	*32.4*	*29.7*	*34.4*	*31.0*	*24.0*	*-*
connected to French	*Σ*	*22*	*22*	*18*	*18*	*14*	*17*	*17*	*17*	*18*	*19*	*15*	*16*	*15*	*12*	*-45.4%*
connected to UK	*Σ*	*10*	*7*	*9*	*10*	*6*	*5*	*6*	*7*	*5*	*5*	*6*	*7*	*3*	*3*	*-70.0%*
as of British	*Σ*	***16***	***20***	***23***	***22***	***22***	***22***	***18***	***21***	***22***	***19***	***21***	***20***	***17***	***15***	***-6.3%***
	%	*21.1*	*24.7*	*29.5*	*27.8*	*31.4*	*31.4*	*28.1*	*30.9*	*31.0*	*27.9*	*32.8*	*32.8*	*29.3*	*30.0*	*-*
connected to French	*Σ*	*11*	*16*	*18*	*16*	*17*	*18*	*14*	*15*	*18*	*14*	*14*	*13*	*14*	*13*	*+18.2%*
connected to German	*Σ*	*8*	*6*	*7*	*8*	*5*	*5*	*4*	*7*	*7*	*7*	*7*	*7*	*3*	*3*	*-62.5%*
Cross-national board directors	**Σ**	**43**	**41**	**46**	**45**	**40**	**40**	**39**	**40**	**38**	**37**	**35**	**34**	**33**	**29**	**-32.6%**

Number of cross-national ties	Number of company pairs located in two different countries and sharing at least one board member, whatever the number of board member in common; example: we count one tie instead of two when the company i shares at least one board member with the company j
Number of cross-national directors	Number of directors holding one or more board positions in each of at least two countries of the sample

Table 9

Table 9 Degree centralities and centralization of the cross-national corporate network based on shared directors

		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Median	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maximum	%	3.2	4.0	3.6	3.6	2.8	2.8	2.4	2.4	2.0	2.8	2.8	2.4	2.0	2.0
Minimum	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Firms with a degree centrality of 0%	Σ	174	169	172	171	180	180	186	182	179	182	186	189	192	200
	%	69.6	67.6	68.8	68.4	72.0	72.0	74.4	72.8	71.6	72.8	74.4	75.6	76.8	80.0
Firms with a degree centrality ≥ 2.5%	Σ	2	3	1	1	1	1	-	-	-	1	1	-	-	-
	%	0.8	1.2	0.4	0.4	0.4	0.4	-	-	-	0.4	0.4	-	-	-
Centralization	-	0.0302	0.0380	0.0340	0.0339	0.0264	0.0265	0.0226	0.0225	0.0184	0.0266	0.0268	0.0228	0.0189	0.0190
Density	-	0.0011	0.0012	0.0012	0.0012	0.0010	0.0009	0.0009	0.0009	0.0009	0.0009	0.0008	0.0007	0.0007	0.0006

NB: analysis based on adjacency matrices

Table 10 Companies with an average degree centrality ≥1% in the cross-national corporate network

Company	**Country**	**Average degree centrality** (in %)	**Number of years in the top 10**
Airbus (fka EADS)	Germany	2.61	14
Engie	France	1.32	7
Siemens	Germany	1.26	11
AstraZeneca	United Kingdom	1.00	7
AXA	France	1.00	7
Vivendi	France	1.00	11

NB: analysis based on adjacency matrices; fka = formerly known as