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Business transactions and ownership ties between firms

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ABSTRACT

In this study we investigate the creation and persistence of interfirm ties in a large-scale business transaction network. Transaction ties, firms buying or selling products or services can be the outcome of pure business motivations, but the social connections of owners or the geographical location of companies may also influence their development. We build the transaction and the ownership networks of firms in Hungary for 2016 and 2017 from two administrative datasets and identify multi-layer network motifs to predict the creation and persistence of business transactions. We show that direct or indirect relationships in this two-layered network contribute to both the creation and persistence of business transaction ties. We find a positive, but smaller impact of geographic proximity and industrial similarity of firms. For our estimations, we utilize loglinear models and emphasize their efficiency in predicting links in such large networks. We contribute to the literature by illustrating business connection patterns in a nationwide multilayer interfirm network.

JEL codes: L14

Keywords: transaction network, ownership network, multilayer network, network motifs, tie creation, tie persistence

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Üzleti tranzakciók és tulajdonosi kapcsolatok cégek között

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ÖSSZEFOGLALÓ

Tanulmányunkban a cégek közötti kapcsolatok létrejöttét és fennmaradását vizsgáljuk egy nagyméretű üzleti tranzakciós hálózatban. Tranzakciós kapcsolatok – azaz termékek vagy szolgáltatások vásárlása vagy értékesítése – létrejöhetnek tisztán üzleti motivációk eredményeként, de a tulajdonosok társadalmi kapcsolatai és a vállalatok földrajzi elhelyezkedése is befolyásolhatja kialakulásukat. A magyarországi cégek tranzakciós és tulajdonosi hálózatait két adminisztratív adatbázisból felhasználásával hozzuk létre a 2016-2017 évekre vonatkozóan. Ezekben többszintű hálózati motívumokat (motifs) azonosítunk, és ezekkel magyarázzuk az üzleti tranzakciók létrejöttét és fennmaradását. Azt találjuk, hogy a kétszintű hálózatban azonosított közvetlen vagy közvetett kapcsolatok hozzájárulnak az üzleti tranzakciós kapcsolatok létrejöttéhez és fennmaradásához egyaránt. Pozitív, de kisebb hatást találunk a földrajzi közelség és a cégek ipari hasonlósága kapcsán. Becsléseink során loglineáris modelleket alkalmaztunk, melyek hatékonynak bizonyultak a kapcsolatok létrejöttének becslésére ilyen nagy hálózatokban lévő. Tanulmányunkban egy országos szintű többrétegű tranzakciós hálózat mintázatainak elemzésével járulunk hozzá a szakirodalomhoz.

JEL: L14

Kulcsszavak: tranzakciós hálózat, tulajdonosi hálózat, többszintű hálózatok, hálózati motívumok, kapcsolatok kialakulása, kapcsolatok fennmaradása

1. Introduction

Economic production happens through the interaction of firms. Studying these interfirm interactions – such as transactions of firms buying or selling products or services to another firm – allows us to understand production processes (Atalay et al., 2011; McNerney et al., 2022), supply chain mechanisms (Arora & Brintrup, 2021; Todo et al., 2016) or economic shock propagation (Diem et al., 2021; Inoue & Todo, 2019; Pálovics et al., 2021).

The web of relationships between companies is essential for markets, as they convey information, resources, and knowledge within a social structure. Before the millennium, studies on business networks were mostly preoccupied with the buyer and supplier relationships of a handful of firms and mainly took an ego-network perspective (e.g. Provan 1993). However, the availability of large-scale datasets on firm-to-firm interactions enables researchers to analyze the complex structures of these networks (see Fujiwara and Aoyama 2010; Atalay et al. 2011). Nodes of such networks represent companies and linkages between them indicate a business transaction, such as buying or selling a product.

Business transaction networks have noteworthy features. Their degree distribution is highly unequal and is similar to scale-free networks (Fujiwara & Aoyama, 2010; Jaeheon & Sang, 2016; Mizuno et al., 2014; Ohnishi et al., 2009). As firm size and market strategy determines buyer and supplier connections, larger companies with a diverse product portfolio have more business transaction ties. The geographic proximity of firms is another strong predictor of business ties (Bernard et al., 2019), as establishing and maintaining business connections is easier and cheaper over short distances. Therefore, productive firms tended to have more distant business partners than less productive ones (Bernard et al., 2019; Todo et al., 2016). Furthermore, business ties of firms are largely influenced by the industry they belong to. Instead of horizontal, intra-industry connections, business transaction networks tend to show a strong hierarchy (Kichikawa et al., 2019) driven by supply chains of production, however, the strength of this hierarchy varies by industry (Luo et al., 2012).

While previous works provided evidence on the structural features, geography, industrial hierarchy, and position-related outcomes of business networks, we still have limited understanding of the underlying mechanisms that drive transaction network tie formation between firms. In other words, we know less about features that support the observation of business network ties between companies. Therefore, this study takes a novel perspective to explore the drivers of tie creation and persistence in interfirm business networks. By doing so, we contribute to the literature on network formation in the following ways.

First, we take a multilayer network approach (Kivelä et al., 2014) and study the influence of co-ownership relations on business ties. Ownership ties signal power, influence, and trust between firms (Takes et al., 2018). Besides geographical proximity and industrial similarity of companies, we expect that ownership significantly enhances business tie formation and promotes reduced environmental uncertainty and predictable circumstances based on control and mutual learning.

Second, to assess the importance of multilayer network features on business tie formation, we focus on network motifs (Ohnishi et al., 2010). Network motifs are small subgraph patterns that occur significantly more frequently than random chance, and as such, they carry information about the underlying mechanisms of the system (Alon, 2007). So far, studies on transaction network motifs showed that open, V-shaped triads are relatively frequent, while transitive triads are relatively sparse in business transaction networks (Borsos & Stancsics, 2020; Ohnishi et al., 2010). In particular, we analyze network motif configurations to reveal the effect of direct and indirect co-ownership and transaction linkages on the formation of business transaction ties.

Third, we separately test the mechanisms of business tie creation and tie persistence. The distinction is important, because the motivations, related costs, constraints, and uncertainties are different for creating and persisting relationships (Juhász & Lengyel, 2018; Wilson, 1995; Zerbini & Castaldo, 2007). Even though these underlying factors are hardly observable, by assessing the importance of different factors such as geography or industrial similarity for tie creation and tie persistence, we can infer their importance for business tie formation. This way, such differentiation can reveal the micro-foundations of business network development.

Fourth, to test the influence of geography, industrial similarity, and co-ownership through multi-level network motifs on business tie formation, we use log-linear models. In contrast to classic regression models on tie formation or simulation-based methods like ERGMs or SAOMs (Block et al., 2019; Broekel et al., 2014), log-linear models are fast and efficient to predict links in large networks as they analyze associations between nominal variables in contingency tables.

We proceed as follows. In section 2, we summarize the literature about mechanisms that can influence the creation and persistence of business transaction ties and present the differences in economic and social motivations. Based on this theoretical framework, we formulate our hypotheses. Section 3 introduces the data source, data management, and applied methodologies, including details about network construction and estimation strategies. In section 4, we present and discuss our empirical results. The paper concludes with a discussion that highlights our contribution to the social network literature and outlines limitations and future research possibilities.

2. Formation of business transaction ties

2.1. Pure economic motivations

Analyzing business transaction networks is an emerging field, and it is tempting to use the well-established measures and concepts of social network analysis to explain business ties. Social networks usually have a high level of transitivity, as friends of friends are likely to be friends; and are reciprocal, meaning that social connections reflect mutual interest (Snijders, 2011). Homophily is another key driving force, as social relations are more likely between similar entities (McPherson, Smith-Lovin, and Cook 2001; Rivera, Soderstrom, and Uzzi 2010).

However, the mechanisms generating business transactions and social connections are fundamentally different. Firms produce different products and services that can be understood by the mechanisms of economies to scale and economies to scope (Tirole, 1988). Necessary inputs that are not produced by the firm itself are bought from the market. Buying products or services is driven by the principle of substitution and complementarity. If the products of two firms *A* and *B* are complements, the buyer of *A*'s products will be likely to buy from *B* as well, and the buyer of *B* will be likely to buy from *A*. This complementarity, however, results in V-shape open triangles or square-like structures (of two buyers and two producers) instead of closed triads. In this sense, transaction networks are rather similar to functional networks, e.g. protein networks, with the overrepresentation of even paths (Mattsson et al., 2021), than social networks.

2.2. Social ties and economic interaction

Besides the illustration of the difference between social and business networks, a large body of literature show a crucial influence of embeddedness in social structures on economic activity based on the pioneering work of Granovetter (1985). An important dimension of embeddedness is trust, as information is often imperfect and asymmetric, and incomplete contracts necessarily create uncertainty and room for opportunistic behavior (Williamson, 1985). Therefore, recommendations from buyers and suppliers are important sources of new businesses in service sectors (Bryson et al., 1993). Trust supports information exchange that may decrease the likelihood of business problems such as suppliers' deviance from timely delivery (Perry, 2012). Another case is when an order that was agreed upon previously without a written contract is sent back to the supplier. This causes a loss of business credibility of the buyer at the particular supplier, and this information reaches other ones as well, who may know the first supplier (Murthy & Paul, 2017). Reliance on trust in partners also becomes crucial when the supplier needs to decide whether to fulfill an urgent order in the case of a shortage of resources or the buyer decides whether to pay the supplier in case of financial hardship (Uzzi, 1997).

As the above examples illustrate, network connections contribute to trust, as having common partners (indirect relationships) creates the opportunity for control by imposing sanctions (tarnishing one's reputation), and for learning about potential partners (Granovetter 1985:490; Buskens and Weesie 2000). However, the relationships that support trust are not necessarily pure transactions, but most likely more complex social connections. Trust in business may arise from personal friendships, shared values or ethnicity (Kremel et al., 2014; Murthy & Paul, 2017; Sofer & Schnell, 2017), but can emerge in networks of control and power such as interlocked directorates (Mizruchi, 1996; Stearns & Mizruchi, 1986). Consequently, to understand the mechanisms of tie formation in business transaction networks, we have to consider the embeddedness of firms in other relational structures. In this respect, we focus on ownership ties hereby defined as co-ownership connections of individuals across firms.

Ownership ties are social connections that signal high influence, as they represent the most direct control over corporate decision-making (Glattfelder & Battiston, 2009; Kogut & Walker, 2001; Mizruchi, 1996; Takes et al., 2018; Vitali et al., 2011). Thus, ownership relations represent a power of control that can limit the potential opportunistic behavior of partners. Furthermore, common ownership of the parties involved eliminates the economic motivation for opportunistic behavior, as it would harm the economic interests of the group as a whole. In addition to direct control, co-ownership relationships are considered as a communication structure advancing the reproduction of existing beliefs and the diffusion of new ideas (Burris, 2005; Carroll et al., 2010; Mizruchi, 1996). Consequently, ownership relations are a crucial source of information exchange (Hillman & Dalziel, 2003), and as such, they improve the legitimation and reputation of firms (Galaskiewicz, 1985) and enhance the firms' cooptation of environmental uncertainty.

2.3. Drivers of tie creation and tie persistence

Studying the mechanisms that support the appearance of interfirm connections over time, it is important to distinguish the drivers of tie creation and tie persistence. The underlying motivations to establish a new tie or to maintain connections can involve different costs, constraints, and uncertainties (Wilson, 1995; Zerbini & Castaldo, 2007).

Zerbini and Castaldo (2007) argue that the creation of business relationships is based on economic advantages, but they also require trust and collaborative behavior. Later, social connections stabilize the relationship, allowing its expansion. In the long run, persistence of business ties mainly depends on the quality of social exchanges and cooperation. Wilson (1995) argues that reputation, trust, and performance are key criteria for selecting partners, while structural bonds, commitment and cooperation are important for the persistence of relationships. Consequently, shared ties may facilitate cooperation and promote both tie formation and persistence (Dahlander & McFarland, 2013). To infer on the hardly observable micro-motivations of firms to create and persist business ties, we formulate multiple hypotheses based on the related literature in the following.

From a geographic perspective, interfirm business transactions between distant locations are associated with higher trade costs, as a result of increased transportation costs (Krugman, 1991). In addition, geographic proximity eases communication with business partners. Despite the development of IT solutions that support communication over long distances, face-to-face interactions remained important in developing trust and valuable social connections that channel information and knowledge (Jones, 2007; Leamer & Storper, 2014). Personal interactions between individuals inside supply chains were shown to improve firm performance, as they increase firms' opportunity to find a good supplier, and to work efficiently with their existing suppliers (Bernard et al., 2019). Therefore, we formulate the following two hypotheses to test the role of geographic proximity in business tie formation:

H1a: The creation of business transaction ties is more likely between geographically proximate firms.

H1b: The persistence of business transaction ties is more likely between geographically proximate firms.

While geographic proximity enhances both business ties and social network connections, industrial similarity of companies may influence business ties differently. As industrial classification is based on product similarity, firms within the same industry are more likely to be competitors, and business connections between them are less likely. This results in heterogeneous business transaction ties between companies in terms of industries (Fujiwara & Aoyama, 2010).

Relatedness of industries refers to the fact that industries are not identical, but share commonalities in a technological sense (Frenken et al., 2007; Hidalgo, 2021). Relatedness facilitates information and knowledge sharing as firms can easily understand each other based on their close knowledge basis and similar capabilities (Brennecke & Rank, 2017, 2016), yet they are different enough to be interested in cooperation (Broekel & Brachert, 2015; Nooteboom, 2000). In the context of business transaction ties, we can expect that firms in related industries face lower levels of uncertainty for new tie creation as they have a better understanding of the capabilities and production processes of the other. Moreover, relatedness can reduce the costs to strengthen connections through repeated interactions. Accordingly, we formulate the following two hypotheses:

H2a: The creation of business transaction ties is more likely between firms in related industries.

H2b: The persistence of business transaction ties is more likely between firms in related industries.

Direct ownership ties between firms represent a power of direct control between firms and as such, it also mitigates the economic motivations for opportunistic behavior. In this respect, we expect that direct ownership through individual co-ownership ties are increasing the likelihood of both business transaction tie creation and persistence.

H3a: The creation of business transaction ties is more likely between firms directly connected by co-ownership ties.

H3b: The persistence of business transaction ties is more likely between firms directly connected by co-ownership ties.

To highlight the importance of more complex forms of relational embeddedness, we argue that indirect relationships between firms also facilitate the development of business connections. Three different network motifs of indirect contact are possible to consider in our multiplex network structure: (1) an indirect ownership relation (2) an indirect transaction relation, and (3) a "mixed" transaction-ownership indirect connection.

Indirect ownership ties exist between firms, in case they are not connected by owners directly, but both firms are connected to a third intermediary. These common owners do not need to be the same people; the intermediary firm may have more owners, of which one owns one of the potential partners, and the other owns the other potential partner. In this case, we assume that our arguments about the lack of motivations for opportunistic behavior in case of direct ownership (H3a and H3b) are transitive over the indirect ownership relations. Thus, we expect that:

H4.1a Indirect ownership ties facilitate the creation of direct business transaction ties.

H4.1b Indirect ownership ties facilitate the persistence of direct business transaction ties.

Indirect transaction ties represent the emergence of triads in the transaction networks, which are shown to be relatively scarce due to the hierarchical nature of value chains (Kichikawa et al., 2019; Luo et al., 2012). However, there are still instances, when they easily appear, for example, when a supplier and a buyer in manufacturing may rely on a common partner providing business services to them, or they may sell their products to a common wholesale company. We also argued that transaction relationships are essential sources of business information and trust (e.g. Murthy and Paul 2017), therefore we suggest the following two hypotheses:

H4.2a Indirect business transaction ties facilitate the creation of direct business transaction ties.

H4.2b Indirect business transaction ties facilitate the persistence of direct business transaction ties.

Through indirect mixed ties we aim to capture the role of indirect connections in multiplex settings on direct business transactions. In case firm A has a transaction tie with firm B, and firm B has a common owner with firm C. We investigate whether the creation and persistence of a transaction link (triadic closure) between firm A and firm C are facilitated by the mixed relations in this V-shape triad. In such cases, ownership relations transmit reliable information on the quality of work of the potential partner (from firm B to firm C about firm A), but it also represents a power of control. If the partner does not meet the expectations, it risks losing its both prospective and existing business partners. To test such mechanisms behind business tie formation, we formulate the following two hypotheses:

H4.3a Indirect mixed (transaction-ownership) ties facilitate the creation of direct business transaction ties.

H4.3b Indirect mixed (transaction-ownership) ties facilitate the persistence of direct business transaction ties.

3. Data and methods

3.1 Data sources and network construction

To uncover the drivers of business tie formation in a large-scale interfirm network, we combine two key data sources. We obtained ownership information on companies from the firm-level database, OPTEN. OPTEN is a Hungarian data provider company that offers annual information and statistics for companies registered in Hungary, including basic financial information, locations and owners.

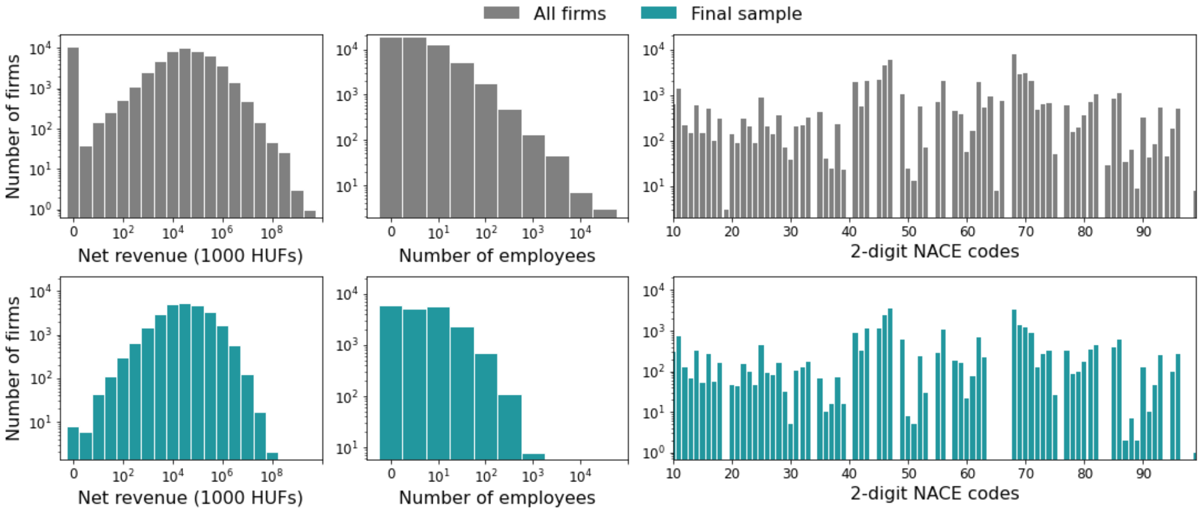
We map the business transactions of firms through VAT reports collected by the National Tax and Customs Administration of Hungary. Firms were obliged to report all their transactions in case the VAT content of their transactions exceeds 1 million HUF in the given year. Therefore, the database in practice should cover all transactions where the yearly pre-tax value exceeds 3.7 million HUF (ca 10,000 EUR) (except those few activities that are exempt from VAT). The dataset is anonymized, but it is connected to the firm-level balance sheet panel database by the Central Statistical Office of Hungary. The database was accessed at the research room facility operated by the Databank of ELKH CERS. We joined the co-ownership ties of firms to the transaction database at this facility.

In the analysis, we only consider companies with a maximum of 50 registered owners that operate in the forms of a joint stock company (Rt. in Hungary), a limited liability company (Kft. in Hungary) or a limited partnership (Bt. in Hungary). These rules filter out associations, funds and other less frequent organization forms that usually include many owners.

As a key aim of our research is to model the influence of co-ownership related connections on business transactions over time, we opt to keep only those firms in the analysis that are observed in the ownership network in any of the two years, and drop all firms that do not have any ownership connections. Furthermore, as we are interested in the social connections between companies signaled by co-ownership ties, we disregard linkages between legal entities. This means that we drop about 18% of ties from the ownership network, where the connection is based on companies directly holding shares in other companies, and keep only those, where the connection is based on a person being owner of two firms. Related descriptives are presented in Supplementary Information SI1. This way we omit the bias in our estimations due to the potential selectivity of the firms that have any ownership connections, however our conclusions will be limited to this sample of firms.

Further, we dropped those firms from our data that reported zero net revenue in both observed years. After these restrictions, we have information on ownership and business transaction ties for 29,116 firms (in 2016 and 2017 together). Figure 1 illustrates the diversity of all firms and this final sample in terms of size and industries. It shows that the final sample represents relatively smaller firms, and that it does not include firms from the financial services sector.

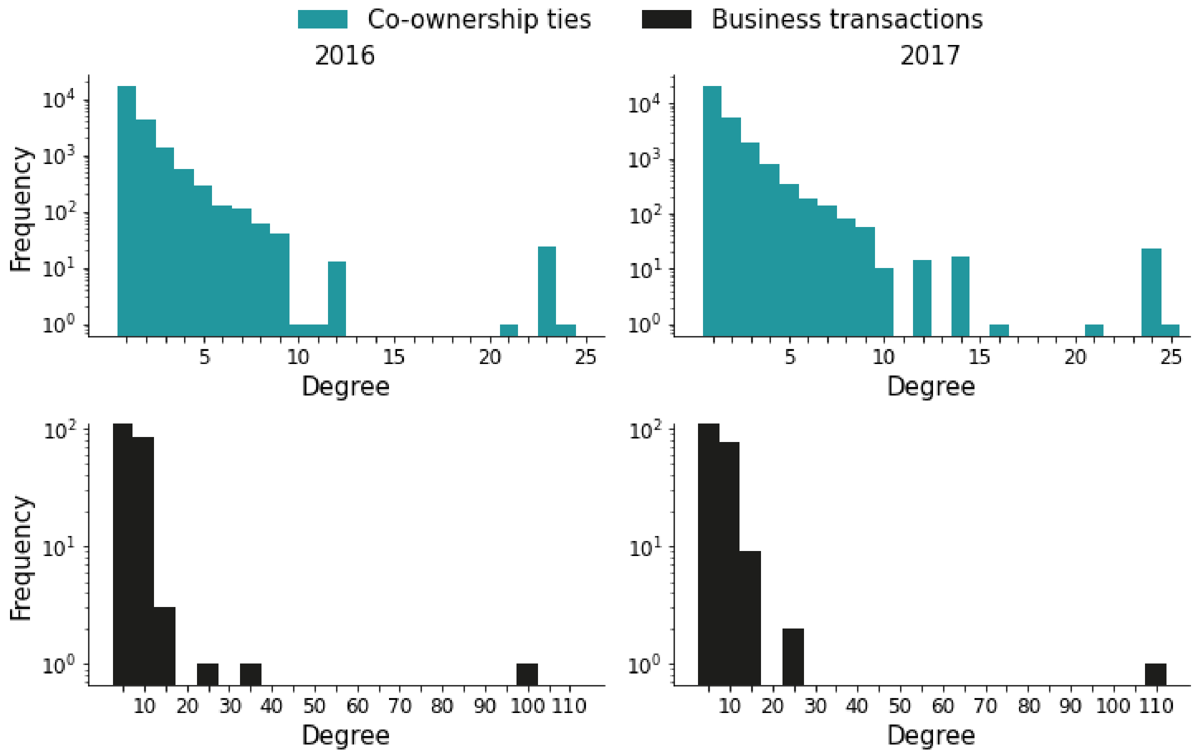
Figure 1 Properties of firms in our sample based on 2016 data



Notes: 'All firms' refer to every company operating in Hungary as a joint stock company, limited liability company and limited partnerships, having less than 50 owners. 'Final sample' refers to the subset of companies having at least one personal ownership tie, and positive revenue in one of the observed years, successfully joined to the business transaction data.

Figure 2 illustrates the degree distribution in the co-ownership network and the business transaction network (only between firms in the final sample) for 2016 and 2017. Given our network construction method, the minimum degree in the ownership network is 1 and only the minority of firms have more than 10 connections. The same set of companies are less connected in the transaction network, however, transaction ties are more concentrated than the ties in the ownership network. While the degree distribution of the co-ownership network is stable over time, the distribution of transaction ties seems to change. SI2 in the Supplementary Information provides descriptive statistics on the number of nodes and edges, and in the ownership and transaction networks, and their overlap and stability.

Figure 2 Distribution of ownership ties and business transactions



Note: The business transaction network is limited to the set of companies present in the ownership network in 2016 or 2017.

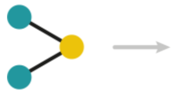
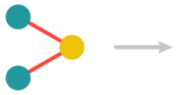
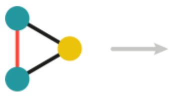
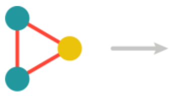
3.2. Motifs and variables

To model the influence of network structural patterns on interfirm business transactions, we focus on a set of network motifs (Takes et al., 2018). As illustrated in Table 1, we model whether transaction ties in 2017 (dashed red lines) develop or sustain between dyads of firms (blue dots) depending on the different multilayer settings that are observed in 2016.

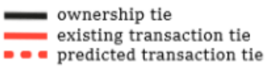
It is important to note that we consider both networks in an undirected setting. Accounting for directionality in the transaction network itself would increase the number of possible motifs from four to twelve. However, these configurations do not differ by our theoretical considerations.

Table 1 also presents the number of observations and the relative frequencies of these motifs for both tie creation and tie persistence. Considering tie creation, only a small portion of firm dyads are connected through such motifs, given the large number of possible links in the network. Given that only a smaller fraction of firms are linked through business transactions in 2016, the relative frequencies of our motifs are higher in case of tie persistence.

Table 1 Multi-level motifs to understand transaction tie formation

2016	2017	Motif name	Observed	Relative frequency
		Motifs behind tie creation		
		Direct ownership	17,148	0.004%
		Indirect ownership	2,022	0.001%
		Indirect transaction	234,748	0.055%
		Indirect mixed	6,949	0.002%
		Motifs behind tie persistence		
		Direct ownership	935	32.01%
		Indirect ownership	41	1.40%
		Indirect transaction	1,115	38.17%
		Indirect mixed	524	17.94%

Notes: The panel "behind tie creation" counts the motifs for all possible pairs of nodes where no transaction edge was observed in 2016, and relative frequency compares these figures to the number of possible pairs of nodes where no transaction edge was observed. The panel "behind tie persistence" counts motifs for dyads with an existing business edge in 2016, and relative frequency compares this number to the number of existing transactions in 2016.



In addition to network structural features, we consider the influence of geographic proximity and industry similarity on the creation and persistence of interfirm business transactions. As our modeling approach requires dichotomized measures, we use the variable same city (1/0) to consider the co-location of firms at the level of cities. More precisely, the same city is based on common zip codes of companies.

With respect to industries, the "same industry" dummy variable indicates that the main activity of the two companies is the same at the 4-digit NACE code level. In this case, two companies work in the same area of production and are assumed to be technologically similar. “Related industry” is a dummy variable indicating that the first two digits of the focal firms’ main activities are identical. This measure assumes that companies do not operate in the same, but in technologically close or related industries, which makes connections easier to create and maintain.

Supplementary Information SI3 provides further descriptives on the geographic distribution of companies and illustrates the distance of interfirm ties in detail. The observed co-ownership ties and business transactions across industries are illustrated in Supplementary Information SI4.

3.3. Estimation strategy

We aim to understand the determinants behind the creation and persistence of business transaction ties. Social network researchers have developed sophisticated models such as ERGMs and SAOMs (Lusher et al., 2013; Snijders, 2011) that are readily available for estimating the structural and node-level factors that predict link formation. However, a distinctive asset of our study is the access to nationwide data that results in big networks (29,116 nodes) even after the limitations of the sample, which makes estimation of these models unfeasible (Block et al., 2019). Therefore, we opt to use a simple dyad-level modeling approach for the entire network, with dependent variable of the presence of links between two firms, and with the independent ones of the multilayer motifs, industrial similarity and geographic proximity. By including the multilayer motifs, we control for triadic effects in the networks. At the same time, we disregard higher-order effects that could have been included e.g. in a SAOM, which might cause our estimates to be biased upwards.

Our dependent variable is a binary variable $T_{ij,t+1}=1$, in case the business transaction tie between two firms (i and j) is present in time $t+1$, and $T_{ij,t+1}=0$ if the tie is not observed. We model tie creation and tie persistence separately and the following two equations illustrate our model settings.

$$pr(T_{ij,t+1} = 1 | \, T_{ijt} = 0) = \beta_1 SC_{ijt} + \beta_2 Rel_{ijt} + \beta_3 SI_{ijt} + \beta_4 DO_{ijt} + \beta_5 IO_{ijt} + \beta_6 IT_{ijt} + \beta_7 IM_{ijt} \quad (1)$$

$$pr(T_{ij,t+1} = 1 | \, T_{ijt} = 1) = \beta_1 SC_{ijt} + \beta_2 Rel_{ijt} + \beta_3 SI_{ijt} + \beta_4 DO_{ijt} + \beta_5 IO_{ijt} + \beta_6 IT_{ijt} + \beta_7 IM_{ijt} \quad (2)$$

where SC_{ijt} indicates whether firm *i* and *j* are in the same city, Rel_{ijt} represents the relatedness of firms *i* and *j*, and SI_{ijt} indicates whether firms operate in the same industry. DO_{ijt} stands for the direct ownership connection between firm *i* and *j*, IO_{ijt} represents indirect ownership relations between firms, IT_{ijt} stands for indirect transaction ties and IM_{ijt} indicates whether firm *i* and *j* are connected through indirect, mixed ownership-transaction relations. The model setting of equation (2) focuses on transaction ties that were present in the previous period. However, the estimation of equation (1) requires considering all the potential connections between companies, which is approximately 420 million possible connections. Thus, instead of the apparent logistic regression approach, we propose the use of log-linear models to make the estimation faster and easier.

Log-linear models are used to analyze associations between nominal variables. They estimate the cell frequencies in contingency tables using the interactions of the defining variables. If we specify a log-linear model with two-way interactions, it directly corresponds to a logistic regression model (Von Eye et al., 2012). Its parameters (log-odds ratios) are also interpreted similarly to logit regressions. We profit on the feature of loglinear models that the estimation uses a table, with the size (number of cells) being only the combination of the categories of the examined variables (144 observations in our case) that is independent from the size of the network itself. Therefore, it is much more efficient than running a logit regression on the dataset with all possible connections (420 million observations in our case)

We estimate the models described in equations (1-2) on the creation and persistence of business transaction ties in a stepwise manner. First, we estimate a null model, with only adding the parameters of geography (SC_{ij}) and industrial similarity (Rel_{ij} , SI_{ij}). Next, we add our parameter that represent direct (ownership) relation (DO_{ij}). Finally, we complement the model with adding the indirect network structure parameters ($IO_{ij}, IT_{ij}, IM_{ij}$). In each case, we add these variables as main effects, together with all their two-way interactions. Thus, equation (3) describes our full log-linear model.

$$log(\widehat{m}) = \lambda + \lambda^{T} + \lambda^{DO} + \lambda^{IO} + \lambda^{IM} + \lambda^{IT} + \lambda^{Rel} + \lambda^{SI} + \lambda^{SC} + \lambda^{T\#DO} + \lambda^{T\#IO} + \lambda^{T\#IM} + \lambda^{T\#IT} + \lambda^{T\#Rel} + \lambda^{T\#SI} + \lambda^{T\#SC} + \lambda^{DO\#IM} + \lambda^{DO\#IT} + \lambda^{DO\#Rel} + \lambda^{DO\#SI} + \lambda^{DO\#SC} + \lambda^{IO\#IM} + \lambda^{IO\#IT} + \lambda^{IO\#Rel} + \lambda^{IO\#SI} + \lambda^{IO\#SC} + \lambda^{IM\#IT} + \lambda^{IM\#Rel} + \lambda^{IM\#SI} + \lambda^{IM\#SC} + \lambda^{IT\#Rel} + \lambda^{IT\#SI} + \lambda^{IT\#SC} + \lambda^{Rel\#SC} + \lambda^{SI\#SC} \quad (3)$$

The parameters that describe the influence of the variables on the creation and persistence of ties are the interaction terms with the transaction relationship "T": T#O, T#IO, T#IT, T#Rel, T#SI, and T#SC.

Nevertheless, to check the validity of our results we estimate equations 1 and 2 in a logistic regression framework as well. This is possible on a 10% sample of all possible nodes in case of tie creation, and on the full sample in case of tie persistence.

Beyond testing our hypotheses directly, we extend the above model with three-way interactions. This may enable us to understand, how the different mechanisms contribute to predicting business transactions. A positive interaction may indicate that two mechanisms amplify each other (complementarity), while a negative one may signify supplementary relationship. Loglinear models are usually evaluated based on $\chi 2$ statistics (Benedetti & Brown, 1978; Rudas, 2018). A decrease in the $\chi 2$ statistics can be used to evaluate improvement in model fit, and when this decreases to a nonsignificant level, it suggests that the predictions based on the parameters do not significantly differ from the observed distribution of the table anymore. We will evaluate the possibility of this extension based on this statistic.

4. Results

4.1. Creation of business ties

To identify factors behind business transaction tie formation, we use different log-linear model settings. We begin by focusing on new business tie formation and present a null model (Model 1 in Table 2) with variables only on the geographic proximity and industrial similarity of firms. We include network structural effects stepwise. First, we control for the influence of direct ownership ties between firms (Model 2), then we assess the importance of indirect connections on new direct business transactions (Model 3). Chi-square test of Model 3 indicates that the predicted distribution of observations still significantly differs from the observed distribution, therefore, addition of further effects is desirable to improve the predicting power of our model. Accordingly, we add all three-way interaction effects to the model (see Table 2 Model 4). The significant likelihood-ratio test supports the improved predictive power of this model compared to the previous one. Therefore, we consider this model as our preferred specification on new business tie creation for testing our hypotheses. The chi-square test of this last model is still significant, suggesting that even further terms could have been added to the model. We do not follow this lead as adding further effects would make the interpretation of the results overly complicated. Moreover, the decreased deviance of the model together with the decreased degrees of freedom suggest that this model is also close to the statistical capacity of prediction.

The two-way effects of “business tie creation” with all other variables describe the extent to which the presence of the motifs is associated with new business tie creation. These are the coefficients shown in Table 2 in terms of log-odds. Thus, the parameter of the same city variable in Model 4 indicates that the probability of new business tie creation is by $e^{3.758} = 42.9$ times increased, if two firms are located in the same city. Results indicate that operating in the same city and in related industries increase the probability of business tie creation corresponding to H1a and H2a respectively. The variable same industry is also positive and significant in our best, final model (Model 4) on new business tie creation. This suggests that physical proximity and similar industrial knowledge support the development of new business connections.

Direct ownership is related to an increased probability of new business tie formation in all model specifications, confirming H3a. Further, we also find such a positive relationship for indirect ownership connections, corresponding to H4.1a. This suggests that ownership ties are influential for business development. Furthermore, the effects of these motifs are higher by an order of magnitude than the effects of geography and industrial similarity. Indirect transaction ties also increase the likelihood of new tie formation in line with H4.2a suggesting that embeddedness in the business network enhances further connections. In Model 4 we also observe that firms indirectly connected through mixed ownership and transaction ties are more likely to create new business connections as expected in H4.3a. Logistic regression estimates corresponding to models 1-3 that were run on a 10% sample as robustness check leads to similar conclusions (see SI5. in Supplementary Information).

Table 2 Key coefficients of log-linear models on new business tie creation

	Model (1)	Model (2)	Model (3)	Model (4)
Business tie creation x				
Same city	4.426***	2.721***	2.404***	3.758***
	(0.060)	(0.119)	(0.129)	(0.099)
Related industry	1.127***	0.948***	0.681***	0.814***
	(0.085)	(0.086)	(0.088)	(0.121)
Same industry	1.145***	0.282**	-0.023	0.746***
	(0.106)	(0.112)	(0.113)	(0.168)
Direct ownership		5.996***	5.862***	8.218***
		(0.131)	(0.147)	(0.141)
Indirect ownership			5.286***	7.186***
			(0.319)	(0.520)
Indirect transaction			5.711***	6.245***
			(0.070)	(0.076)
Indirect mixed			-2.483***	6.362***
			(0.129)	(0.286)
Model statistics				
Deviance	2.1E+09	1.76E+09	6362.0	173.0
d.f.	134	129	109	65
p value (LR test)		0.000	0.000	0.000
p value (Chi2 test)	0.000	0.000	0.000	0.000

Source: Authors' own construction

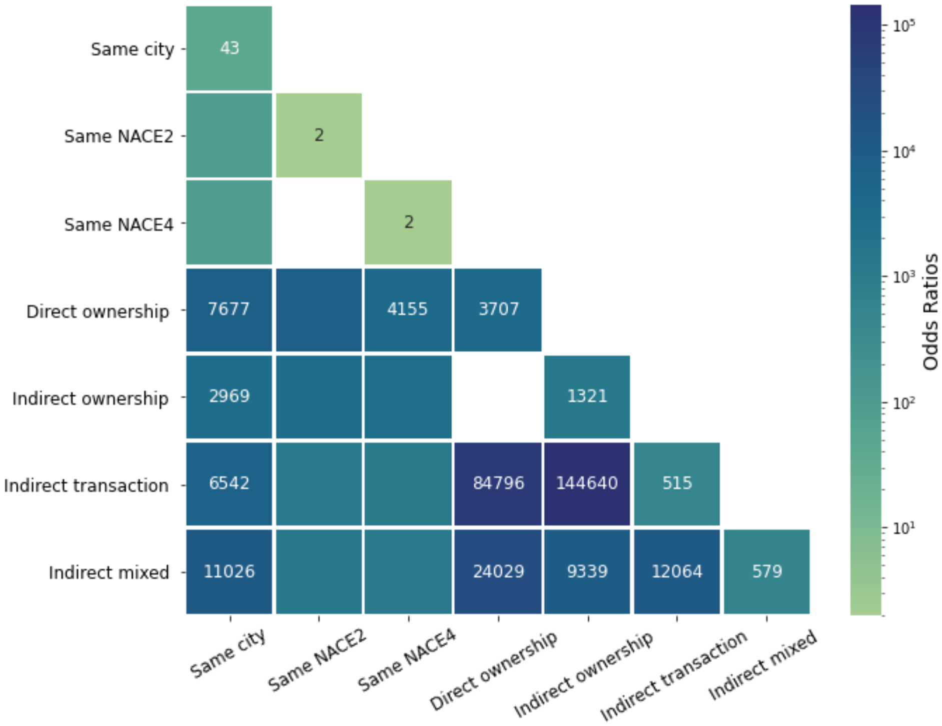
Notes: Parameters of loglinear models, standard errors in parentheses, * $p<0.1$, ** $p<0.05$, *** $p<0.01$

Including three-way interactions to our final, preferred model enables us to evaluate the combination of effects on new business tie creation, such as how the effects of geographic proximity or industrial similarity add on each other in predicting business transactions. These coefficients are listed in the non-diagonal cells of the table in SI6, where the diagonal repeats the two-way effects from Table 2 Model 4. We see that all significant non-diagonal elements are negative, indicating a "diminishing return" on the examined effects. This suggests that the additional effect of a motif is always smaller, if another motif is already present compared to the case when it appears alone.

Figure 3 illustrates the odds ratios calculated from our final model. Cells can be understood as if no other effect is present, being in the same city is associated with a 43-fold increase in the probability of business tie creation. If no other effect is present, having common owners is associated with a 3707-fold increase in the probability of tie creation. Having common owners *and* being in the same city together is associated with a 7677-fold increase in the probability of business tie creation. The heatmap suggests that the probability to create a new business tie is the highest in case two firms are indirectly connected across multiple network layers, namely they have indirect ownership and indirect transaction ties.

Odds ratios are not presented numerically in the cells of Figure 3 if the interaction effects are not significant. We can observe that there are significant negative interactions between (1) the different motifs representing network connections, and (2) between geographic proximity and the network connections. However, there is no such interaction between the industry variables and the indirect network motifs. This suggests a supplementary relationship (e.g., in providing trust) between indirect relations and physical closeness that we do not observe between the industrial structure and the indirect relationships.

Figure 3 Odds ratios calculated from the significant parameters of the three-way interaction model



Notes: Colors correspond to the predicted probabilities calculated from the main effects and interaction effects of model 4. The underlying interaction coefficients are listed in Supplementary Information SI 6. The predicted probabilities are displayed numerically only in cells, where both the corresponding main effects and the interaction effects are statistically significant.

4.2. Persistence of business ties

Coefficients from log-linear models on the persistence of business transaction ties are presented in Table 3. The structure of models is identical to our models on tie creation. First, we present a null model (Model 5 in Table 3) with variables only on the geographic proximity and industrial similarity of firms. We include direct and indirect network structural effects stepwise in Models 6 and 7. To improve the predicting power of our models, we include three-way interactions to our final setting (see Model 8 of Table 3).

The results indicate that firms in the same city are more likely to persist their business connections, as expected according to H1b. Related or identical industry profiles, however, do not significantly influence the maintenance of connections, thus we cannot confirm H2b. These suggest that geographic proximity matters both for tie creation and persistence, while industrial similarity only influences the creation of new business ties.

Direct ownership ties between firms support the persistence of business transactions, according to H3.b, but indirect ownership does not, contrary to the expectation in H4.1b. This suggests that only direct control and influence through ownership support the maintenance of business ties. Coefficients for indirect transaction ties corresponding to H4.2b are positive and significant for all model settings, meaning that embeddedness in business transaction networks support tie persistence. Indirect mixed ties increase the likelihood to maintain business connections between firms, too, as expected in H4.3b.

It is important to note that effect sizes are much smaller than the ones observed in the context of business tie creation. The parameters are in the range of 0.6-0.7, which correspond to 1.8-2-fold increase in probabilities. The lack of significance of the indirect ownership parameters may also be due to the low number of observed network motifs (causing low statistical power) in the data. Logistic regression equivalents of model 5-7 provide identical estimates to the second digit, underlining that the two specifications are mathematically equivalent (See SI7. In Supplementary Information)

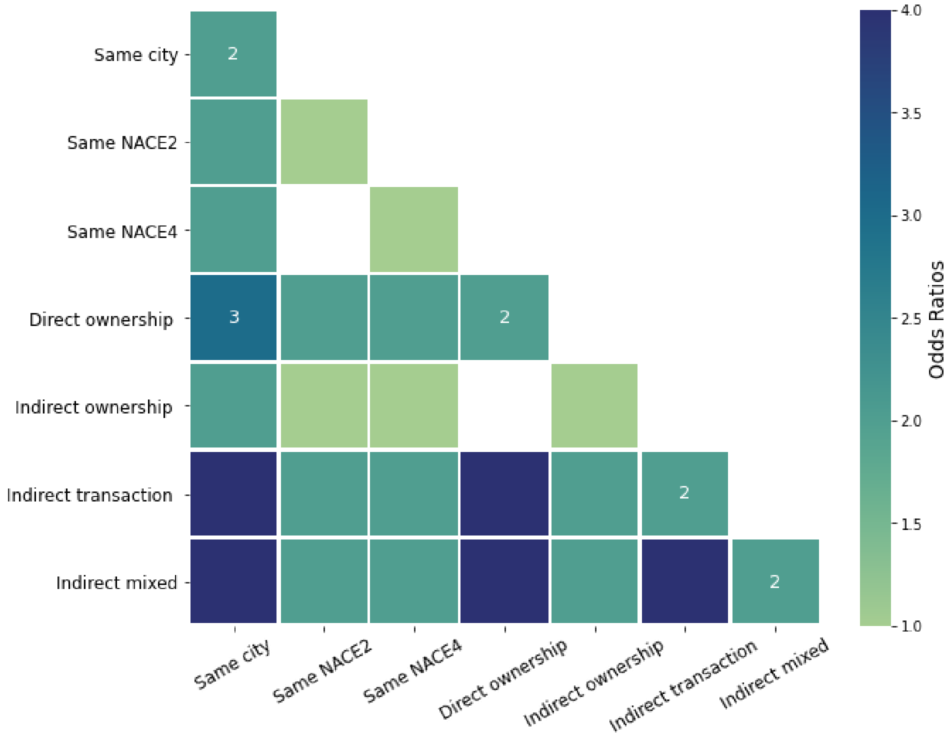
Table 3 Key coefficients of log-linear models on tie business tie persistence

	Model (5)	Model (6)	Model (7)	Model (8)
Business tie x				
Same city	0.621***	0.261***	0.262***	0.677***
	(0.082)	(0.098)	(0.100)	(0.170)
Related industry	0.277**	0.272**	0.155	0.169
	(0.119)	(0.120)	(0.123)	(0.201)
Same industry	0.179	0.111	0.123	0.222
	(0.145)	(0.147)	(0.149)	(0.260)
Direct ownership		0.665***	0.677***	0.726***
		(0.098)	(0.101)	(0.174)
Indirect ownership			0.408	0.864
			(0.332)	(0.687)
Indirect transaction			0.591***	0.687***
			(0.082)	(0.117)
Indirect mixed			0.335***	0.605***
			(0.107)	(0.228)
Model statistics				
Deviance	5501	4514	186.5	100.9
d.f.	134	129	109	65
p value (LR test)	0.000	0.000	0.000	0.000
p value (Chi2 test)	0.000	0.000	0.000	0.003

Notes: Parameters of loglinear models, standard errors in parentheses, * p<0.1, ** p<0.05, *** p<0.01

Despite the chi-squared test of the three-way interaction model (Model 8 of Table 3) suggests including further parameters (four-way interactions), most of the coefficients of the three-way interactions are not significant themselves. As Figure 4 illustrates, we only observe significant three-way interactions with direct ownership and same city parameters, suggesting that both of these increase the probability of business tie persistence. However, if one of these parameters is already present, the positive effect of the second one decreases.

Figure 4 Odds ratios calculated from the significant parameters of the three-way interaction model



Notes: Colors correspond to the predicted probabilities calculated from the main effects and interaction effects of model 8. The underlying interaction coefficients are listed in Supplementary Information SI 8. The predicted probabilities are displayed numerically only in cells, where both the corresponding main effects and the interaction effects are statistically significant.

5. Discussion

Uncovering the drivers of network tie formation is key to understand the evolution of social and economic systems. In this paper, we uniquely build on a social network approach to study the drivers of tie formation in a rather functional business transaction network. Specifically, we combine a large-scale interfirm business transaction data with information on the industry profile, location, and owners of companies to identify factors that support the creation and persistence of business ties. Based on this novel perspective and the extensive dataset, our findings contribute to the literature on social and economic networks in multiple ways.

First, by integrating the literature on co-ownership networks (Takes et al., 2018) and transaction networks (Atalay et al., 2011; Diem et al., 2021; Hazama & Uesugi, 2017; Pálovics et al., 2021) we demonstrate that ownership connections strongly predict business relationships. In particular, we show that direct ownership ties between companies largely increase the likelihood that firms create and maintain business relationships. This finding suggests that social ties across firms as proxies of power and control greatly influence business related decisions.

Second, we contribute to the long discussion on network embeddedness (Granovetter 1985; Uzzi 1997) by illustrating that cohesive network structure in business transaction and ownership networks influence the decisions and business development of companies. By employing several multiplex network motifs, the relevant finding shows that companies more embedded in networks of transactions and ownership ties are more likely to create and maintain their business activity over time. As almost all the tested network motifs supported the creation and persistence of business transaction ties, our work demonstrates that embeddedness in and across network layers has a significant role in business connections. In addition, we show that the different indirect relations together with physical co-location contribute to business relationships in a supplementary way, while the industry structure is a rather independent contributor.

Third, this paper also contributes to the growing literature on relatedness (Hidalgo, 2021) by showing that firms in related industries are more likely to establish business ties. At the same time, industrial similarity does not influence the reappearance of transactions. Additionally, in line with the literature (Bernard et al., 2019), we present that geographic proximity of firms support both the creation and persistence of new business links.

Our paper is not without limitations. Although relationship maintenance does not have a widely accepted definition, and in line with Zerbini and Castaldo (2007) we consider tie persistence as repeated transactions between firms, our measurement is relatively shallow, as we define persistence by having at least one transaction occurring in the next year. Observing repeated transactions on a large pool of firms of all types possibly includes mechanisms like repeatedly choosing the same product from the market without further commitments. This is a significant difference to what tie persistence means in supplier networks of technology-intensive industries between firms and their key suppliers. Therefore, further research would be needed to uncover forces that support a long-term dedication of companies towards their buyers and suppliers. Studying such processes over a longer period would also allow more precise measurement of new tie creation, as re-established connections over multiple years would be possible to identify and distinguish from once established and persisted relations.

In this paper, we also illustrate the usability of log-linear models on network tie formation. Given that the estimation table these models use is independent of the size of the network, they can be handy for simple link prediction tasks in very large networks. Besides their clear benefit of being efficient estimations for large-scale network patterns, , they do not allow us to account for actor decisions and the influence of network, dyad, and node-level factors on tie formation at the same time (Block et al., 2019). This potential extension of our work presents itself as a promising future research avenue.

As the theoretical foundation of this paper applies to business transaction ties in general without distinguishing between buyer and supplier relations, we operate with undirected, unweighted network structures. Beside the usage of directed and weighted ties would significantly increase the number of possible motifs to be tested, it would also enable us to consider the strength of buyer-supplier relationships. This scenario could open fruitful research directions to uncover the consequences of mergers and acquisitions on business transaction networks.

In short, our work contributes to the understanding of network tie formation in complex socioeconomic systems. Based on the social network perspective and combining two large-scale administrative datasets, we focus on business transaction ties and co-ownership relations as proxies of control and information. We integrate these relations in network motifs to uncover the role of multilayer network ties in the creation and maintenance of business relationships. We demonstrate that both direct or indirect ties in our multilayer network predict the creation and maintenance of economic transactions, as well as geographic and industrial proximity. We hope that our work inspires more research analyzing multilayer relations to understand complex socioeconomic phenomena.

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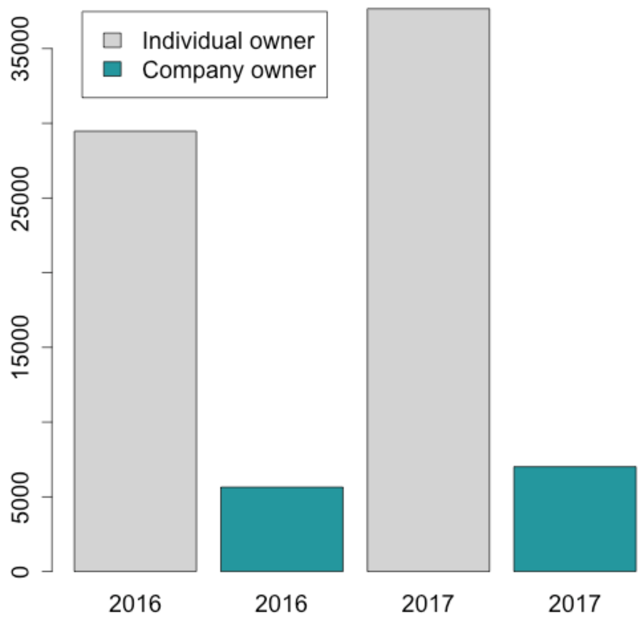
Supplementary Information

S1. Type of ownership ties

As we argue that ownership ties represent a special type of social connections that signal power and control, we choose to focus only on co-ownership based on individuals. Figure 1 illustrates that most of the connections are based on co-ownership through a person and through legal entities.

Figure 1 Ownership connections based on individual and company owners



Source: Authors' own construction

SI 2. Descriptive statistics of of the transaction and ownership networks

Table 1 illustrates the number of nodes and edges in the co-ownership network, in the original transaction network, and in the "limited" transaction network, after dropping the firms that did not have any ownership connections. In general, the transaction network is larger and denser than the co-ownership network. However, limiting the transaction network to the set of nodes observed in the ownership network results in a smaller and less dense subgraph of the transactions network

Table 1 Descriptives of the networks

	Number of nodes	Number of edges
Co-ownership network, 2016	23,602	18,083
Co-ownership network, 2017	29,116	22,900
Full transaction network, 2016	93,555	222,395
Full transaction network, 2017	112,278	254,881
Limited transaction network, 2016	3,399	2,921
Limited transaction network, 2017	3,495	3,051

Notes: Full transaction network refers to the entire network based on VAT return data. Limited transaction network is the subgraph of the entire transaction network between nodes observed in the ownership network in 2016 or in 2017.

Table 2 presents the persistence of interfirm links over time in the two networks and their overlap. We observe more ownership ties in 2017 than in 2016 and that no such connection disappeared over the observed year. Business transactions between the same set of companies are less stable as only about 46% of them appear in both years. The overlap of connections in the two different interfirm networks is relatively small as only around 5% of company pairs have both co-ownership ties and business transaction ties.

Table 2 Overlap and stability of co-ownership and transaction ties

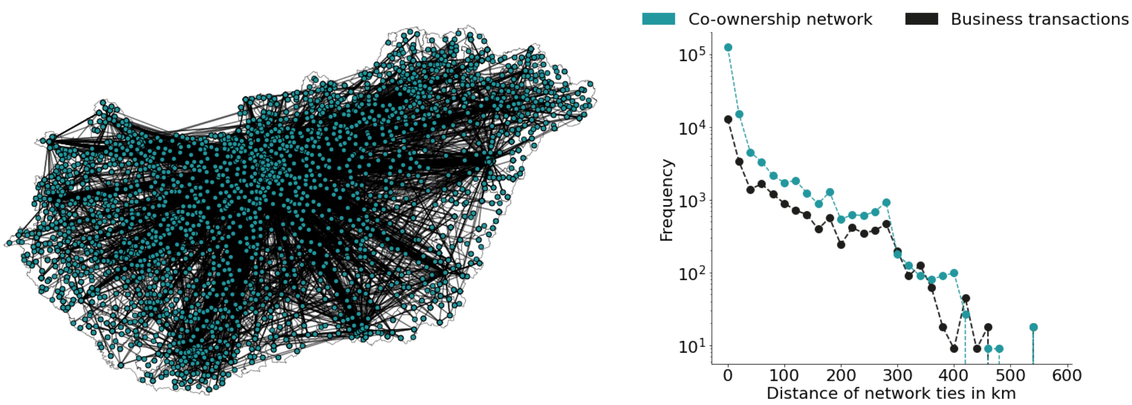
	Number of ties		
	Co-ownership	Business transactions	Overlap
2016	18,083	2,921	935
2017	22,900	3,051	1,046
2016-2017 overlap	18,083	1,378	-

SI3. Geographical distribution of firms

Figure 2 illustrates that ties in the co-ownership network and in the business transaction network have different geographic patterns. There are more co-ownership ties that cover short distances, but over 100 kilometers we observe more business relationships than ownership-based connections.

Figure 2 Geographic dimension of the network

(a) (b)



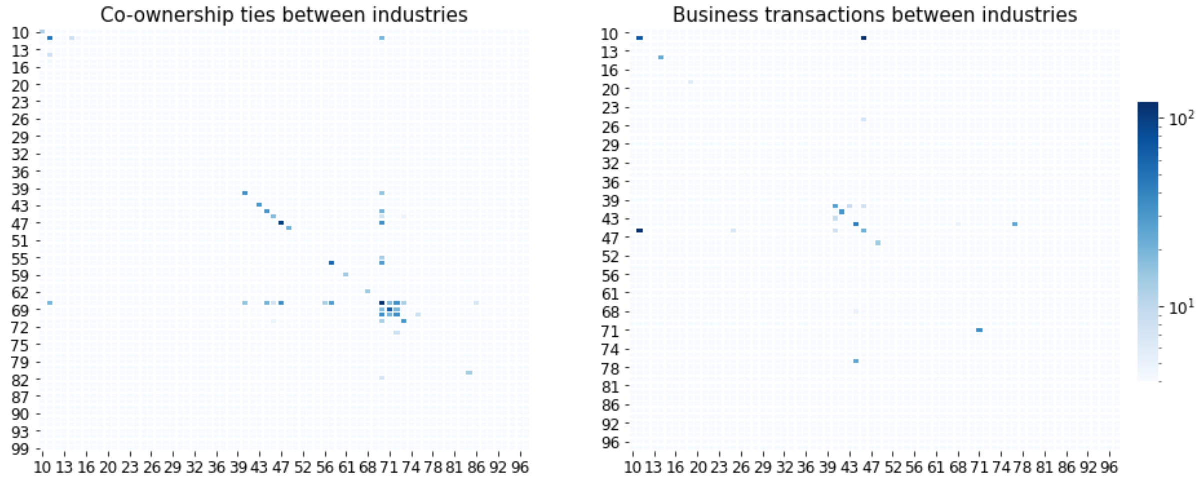
Source: Authors' own construction

Note: Figure 2a maps the co-ownership network of companies from 2016. Figure 2b illustrates distance of ties in the co-ownership and business transaction networks of 2016.

SI4. Co-ownership ties and business transactions across industries

Figure 3 visualizes the density of co-ownership ties and business transactions between industries identified by 2-digit NACE codes. The diagonal is somewhat emphasized on both heatmaps, but the different network ties clearly follow different patterns.

Figure 3 Co-ownership ties and business transactions between 2-digit NACE codes



SI5. Logistic regressions on the creation of business ties

	Dependent variable: creation of transaction tie		
	Model 1	Model 2	Model 3
Same city	4.387***	2.431***	2.454***
	(0.182)	(0.381)	(0.343)
Related industry	1.144***	0.963***	0.753***
	(0.250)	(0.253)	(0.274)
Same industry	2.095***	0.920***	0.554*
	(0.238)	(0.279)	(0.327)
Direct ownership		6.474***	5.502***
		(0.407)	(0.404)
Indirect ownership			5.529***
			(0.901)
Indirect transaction			4.966***
			(0.254)
Indirect mixed			-0.273
			(0.543)
Constant	-12.720***	-12.646***	-12.717***
	(0.089)	(0.086)	(0.088)
Model statistics			
Observations	42,385,618	42,385,618	42,385,618
Log likelihood	-2366	-2198	-2070
AIC	4681	4406	4157

Notes: log-odds parameters, standard errors in parentheses. Run on a 10% random sample of all potential dyads. * $p<0.1$, ** $p<0.05$, *** $p<0.01$

SI6. Selected coefficients of the three-way interaction model on tie creation

	Same city	Related industry	Same industry	Direct ownership	Indirect ownership	Indirect transaction	Indirect mixed
Same City	3.758***	-0.175	-0.171	-3.030***	-2.948***	-1.217***	-0.812***
Related industry		0.814***	NA	-0.256	-1.082	-0.201	-0.068
Same industry			0.746***	-0.632**	-1.597	-0.352	0.170
Direct ownership				8.218***	NA	-3.115***	-4.493***
Indirect ownership					7.186***	-1.549**	-4.406***
Indirect transaction						6.245***	-3.209***
Indirect mixed							6.362***

Notes: The underlying model is presented in Table 5 model 4. * p<0.1, ** p<0.05, *** p<0.01

SI7. Logistic regressions on the persistence of business ties

	Dependent variable: persistence of transaction tie		
	(5)	(6)	(7)
Same city	0.621***	0.261***	0.260***
	(0.082)	(0.098)	(0.100)
Related industry	0.277***	0.272**	0.154
	(0.119)	(0.120)	(0.123)
Same industry	0.179	0.110	0.121
	(0.145)	(0.147)	(0.149)
Direct ownership		0.665***	0.677***
		(0.098)	(0.101)
Indirect ownership			0.414
			(0.333)
Indirect transaction			0.591***
			(0.083)
Indirect mixed			0.330***
			(0.106)
Constant	-0.415***	-0.502***	-0.766***
	(0.050)	(0.052)	(0.062)
Model statistics			
Observations	2921	2921	2921
Log likelihood	-1975	-1952	-1912
AIC	3959	3914	3839

Source: Authors' own construction

Note: log-odds parameters, standard errors in parentheses, * p<0.1, ** p<0.05, *** p<0.01

SI 8 Selected coefficients of the three-way interaction model on tie persistence

	Same city	Related industry	Same industry	Direct ownership	Indirect ownership	Indirect transaction	Indirect mixed
Same city	0.677***	-0.352	0.155	-0.428**	-0.391	-0.162	-0.303
Related industry		0.169	NA	0.221	-0.260	0.137	-0.225
Same industry			0.222	-0.132	-0.066	-0.422	0.410
Direct ownership				0.726***	NA	0.168	0.028
Indirect ownership					0.864	-0.019	-0.315
Indirect transaction						0.687***	-0.311
Indirect mixed							0.605***

Source: Authors' own construction
Notes: The underlying model is presented in Table 5 model 4. * $p<0.1$, ** $p<0.05$, *** $p<0.01$