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"Dissolve the *Keiretsu*, or Die": A longitudinal study of disintermediation in the Japanese automobile manufacturing supply networks

Petr MATOUS
University of Tokyo

TODO Yasuyuki
RIETI

Research Institute of Economy, Trade & Industry, IAA

The Research Institute of Economy, Trade and Industry
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"Dissolve the *Keiretsu*, or Die": A longitudinal study of disintermediation in the Japanese automobile manufacturing supply networks[1,*]

Petr MATOUS

The University of Tokyo

TODO Yasuyuki

RIETI and Waseda University

Abstract

Under unstable global economic conditions and an increasing competition for customers in the emerging markets of lower income countries, Japanese automotive parts manufacturers and assemblers are striving to minimize their procurement costs to remain competitive. Applying stochastic actor-oriented network models to the procurement data of the 100 largest Japanese automobile firms in 2006 and 2011, this study explores (1) the predominant supply chain management strategies in the automobile industry; (2) the dynamics of the manufacturers' revenue; and (3) the interactions between the supply chain structures and revenue. In contrast to supply networks among major companies in other sectors of the Japanese economy, the present results do not reveal a clear tendency to preserve cliquish trading groups. On the contrary, during this challenging economic period, Japanese carmakers sought to bypass traditional intermediary partners in their supply chains and directly access upstream parts manufacturers with lower margins. The firms that pursued this strategy were rewarded with higher revenue. The novel network analytic method specifically discerns that the disintermediation and the diversification of supply chains precede firms' success in sales (rather than vice versa). The results suggest a potential challenge for the traditional *keiretsu* structure among Japanese automotive manufacturers in the new global economic environment.

Keywords: Supply chain management, Network evolution, Network influence, Stochastic actor-oriented models, Automobile manufacturing, Japan

JEL classifications: O14, O33, R12

[1] The quote comes from a former executive vice-chairman of Toyota Motor Corporation Kosuke Shiramizu (reported by Norihiko Shirouzu in "Daihatsu dismantling 'Toyota Way' as market changes", Japan Times, 16 January 2015).

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1. Introduction

The keiretsu system, characterized by long-term relationships between manufacturers and suppliers from the same business group has been widely adopted by Japanese automobile manufacturers and credited for their success. Already in 1939 Toyota organized its first-tier suppliers into an official association and refused to deal directly with 2nd and 3rd tier suppliers. This Toyota's approach was supported by the Japanese government and became soon imitated by other Japanese carmakers (Wada 1992). The logistics and quality control of supplies is significantly simplified if parts are obtained only from a small number of time-proven intermediating partners. Such arrangements enabled Japanese car manufacturers to reduce lead times and manufacturing costs and to achieve high volumes of external production with very lean purchasing departments by international standards (Wada 1992; Kamath and Liker 1994). During the high-growth period of Japanese economy the keiretsu procurement system characterized by a small number of densely interconnected suppliers with little turnover and intensive interactions was praised for effective information-sharing, reducing the costs of monitoring, and keeping generated revenues within a narrow circle of companies (Cooper and Yoshikawa 1994; Holmstrom and Roberts 1998; Lamming 2000; Handfield and Bechtel 2002). Furthermore, dense links among keiretsu suppliers were considered to prevent exploitation by too powerful clients (Holmstrom and Roberts 1998).

After Japan slipped into recession, some commentators started to predict that the role of keiretsu will become even stronger in harsher economic environment because of their role of sharing risks and distributing returns. Others opinionated that the keiretsu model has become outdated for a modern economy in which the challenge is not anymore to get access to resources and maximize production but rather to compete for limited demand by efficiency and price (see Lincoln and Gerlach 2004 for a review of these views). Some qualitative accounts suggest that keiretsu may be already yielding to market mechanisms and open competition to respond to the shift in global demand to price-conscious consumers emerging markets have appeared. Reportedly some Japanese manufacturers started allowing or even recommending their suppliers to develop new links with customers from other industrial groups and not to rely on their old clients (Lamming 2000).

Anecdotally, press reports include a high-positioned representative of major car assemblers accusing keiretsu first-tier suppliers for abusing their guaranteed exclusive position of brokers and reselling with unjustifiably high margins parts cheaply produced by newcomers and firms without a direct link to the major assemblers (Shirouzu 2015). Reports of interlinked suppliers colluding to push their prices beyond reasonable levels to inflate their margins have also emerged (Shirouzu and Shiraki 2014). The need for decreasing procurement costs and any waste across the supply chain arguably particularly intensified during the global financial crisis when safe haven demand inflated the value of the Japanese currency. The Japanese Yen strengthened from 120 yen per US dollar in 2006 to 76 yen in 2011 making cars produced in Japan more expensive on global markets.

Focusing on the period around the global financial crisis (2006-2011), this research aims to quantitatively establish whether the reported cases of diminishing importance of keiretsu are representative of an overall new trend in the structures of manufacturing networks among major Japanese automakers or whether these are just exceptions.

The specific research questions can be categorized into the following two groups.

1. In the studied period, what was the statistically prevalent strategy for supply network management among major Japanese carmakers?

1.1. Are choices of suppliers constrained by firms belonging to the same trade network cliques?

1.2. Are Japanese automakers turning away from intermediaries and trading companies that facilitate access to multiple original part manufacturers?

2. Controlling for these internal network tendencies, what type of supply network management strategy is economically recommendable?

2.1 In terms of revenues, is it advantageous to procure parts through a small number of first-tier suppliers or access a wider range of suppliers directly?

2.2. Does financial success spread among partners? Is it recommendable to partner with firms that are able to generate high revenues or seek firms with minimum margins?

2. Supply networks and revenues: conceptual framework

2.1. Keiretsu in network terms

A typical keiretsu network structure is depicted in Figure 1(1). In this symbolic illustration, the assemblers on the left procure parts via a small number of first-tier suppliers who mediate access to multiple second-tier suppliers and who also cooperate with each other. Direct connections to second-tier suppliers are deliberately avoided and the number of first-tier suppliers is constant as the original partners cannot be abandoned and new ones are never directly added. Cooperation among first-tier suppliers and avoidance of firms that are not connected to the business group creates dense network cliques which are relatively disconnected from each other.

The right-hand side of Figure 1 symbolically depicts the hypothetical departure from the keiretsu system. Assemblers bypass the intermediaries and reach directly to the most suitable suppliers without constraints of their business cliques' affiliation. As result, each client need to maintain more direct procurement links and popular suppliers can serve many clients across the groups.

2.2. The dynamic mechanism of supply networks and firm performance

To quantitatively examine whether traditional mechanisms still shape automobile supply chains in Japan, we need to find out whether firms prefer to have a small number of first-tier suppliers to mediate the procurement of parts from multiple producers and whether firms prefer trading partner from the same clique (indicated by the number of common partners they have with each other). We also want to find out whether such traditional supply chain management brings high revenues in the contemporary context.

However, supply chain management strategies cannot be fully identified only by direct observations of the changing network shapes. At the micro-level, presence of cohesive groups is typically expressed in network terms as a high presence of triangles (i.e., partners of partners are also partners). However, the changing number of triangles alone might not indicate a preference for partners from the same trading clique. Different micro-economic mechanisms can produce triangular patterns in the data. Trivially, the number of incidental triangles will increase with more trading links in the network. Alternatively, there may be substantially more important reasons behind the changing numbers of basic network motifs. For example, if most firms across the network seek the lowest cost suppliers regardless keiretsu boundaries, the best supplier will emerge as a new hub to which many other nodes are connected. New links in the network will likely create triangles that include this supplier even if these new links were not motived by the presence of this mutual business partner. By iteratively simulating the network evolution with actors' varying supply chain management strategies, we aim to uncover the real drivers which most faithfully regenerate the observable reality.

This is a complex task because both supply networks and firm revenues may evolve overtime and influence each other in both directions. The clients' and suppliers' performance may theoretically both influence and be influenced by supply networks. Existing networks may constrain their own evolution. When procurement specialist select from which firm to purchase parts, they may prefer to keep their existing suppliers they have and if necessary expand the procurement volumes through them as was reported in the past (Wada 1992). Procurement decisions may also be influenced by factors beyond the dyadic relationship between supplier and the client. Major Japanese firms may prefer to partner with organizations from the same business groups characterized by dense webs of relationships (Matous, Todo 2014). Alternatively, to prevent collusion or to benefit from diversity of knowledge, automakers may seek independent suppliers who have no trading relationship with their other suppliers. These effects of the present shape of supply networks on their own future evolution is worth exploring in its own right but it is also a source of endogeneity which needs to be controlled for in study of the relationship between the dynamics of supply chains and firm performance. Furthermore, network dynamics can be influenced by the suppliers' and clients' revenue dynamics. Assemblers with larger sales my need to expand their supply chains and financially more successful suppliers may be more attractive. Similarity in performance may also matter—successfully companies may tend to cluster together and such possibility should also be controlled for.

However, the opposite causal direction is also possible. If revenues and the number of suppliers are correlated it may be the case that the supply network structure was the source of the increased performance rather than vice versa.

Untangling the underlying mechanisms is challenging but important. If certain supply chain strategies are found to be associated with financial success, it is important to understand whether certain supply network structure leads to higher revenues (which would be a recommendable strategy to replicate by other ambitious firms) or whether only firms that are already successful consequently tend to reshape their supply chains in a certain way (which would not necessarily provide practical lessons for other companies).

2.3. Revenues per employee

Firm performance in this study is conceptualized in terms of revenues per employee (RPE). The reason for focusing on revenues rather than profits is that profit data depend on the levels of investment. It is problematic to discern whether negative profits reflect mismanagement or a large investment of promising companies. Moreover, because of fluctuating (and unknown levels of) investment, there is no statistical continuity in net profits for the firms in focus during over the observed period (correlation between firms' profits in 2006 and 2011 is R=0.05, p=0.62). Thus, in addition to the theoretical problem of interpreting the meaning of net profits, this complete discontinuity makes it impossible to apply an analytical framework which aims to discern continuously evolving performance trends over time.

In contrast, increasing revenue trends for the same company can be more generally interpreted as performance improvement and decreasing revenues as performance deterioration. Moreover, revenues evolve from year to year in a continuous manner allowing application of a modeling framework that statistically analyzes drivers of continuous evolution over a certain time period.

Naturally, larger firms are more likely to have larger revenues. Therefore, to discern trends in performance of firms of firms of unequal sizes, revenues per employee are used in this paper. However, caution is necessary when comparing the performance of firms in terms of RPE. Even within the same industry RPE may be influenced by the type of business the firm is involved in, specifically the degree to which the firm is production-oriented or trade-oriented. For example, firms that manufacture internally the sold parts are likely to have lower RPE because such production is labor-intensive. In contrast, trading firms and official first-tier suppliers that only add their own margin to products that were manufactured by other firms are likely to have higher RPE. Nevertheless, RPE is a good indicator of longer-term trends over time for each company. For the same company in a certain line of business, increase in RPE is likely to indicate improved financial health, which can be translated into higher profit margins.

3. Methods

3.1. Data

The analysis in this paper is based on trade interaction between the largest 100 firm primarily involved in the automobile sector in Japan (class 301 in Japan Standard Industrial Classification, Rev. March 2002, at the three-digit level, which corresponds to 311 in the present classification). The manufacturers were selected based on the number of their employees in 2006. Trade data from 2006 and 2011, collected by Tokyo Shoko Research, include information on suppliers and clients on each firm (but does not include any information about the volume of these transactions). The data also include the revenues and the number of employees of each firm in the beginning and in the end of this period. The measures are characteristically skewed and therefore their natural log transformations are used in the present analysis, as is commonly done in firm-level econometric studies. Because it is possible to model only probability of discrete changes in the present modeling framework, our measure of firm performance, i.e., log(revenues/employees), was rounded to integer values. This produced an RPE scale with three categories of performance: low, middle, and high. The sample is described in Table 1.

It can be immediately seen with a simple correlation test that the number of suppliers and the revenues per employee are highly correlated (R=0.5, p<0.01). However, it is not possible to discern only from observed correlations whether accessing more suppliers leads to higher revenues, whether more successful companies tend to subsequently expand their supply chain, or neither. A sophisticated modeling is needed to untangle underlying mechanisms behind potentially coevolving supplying networks and the revenues of firms embedded in these networks.

3.2. Analysis: stochastic actor-oriented modeling

After describing the structure of the interfirm networks in 2006 and 2011, we analyze the microprocesses that lead to the observed macro network evolution. Complex supply chain networks cannot be adequately modeled as simple linear chain entities, because of important lateral dependencies between suppliers (Brintrup, Kito et al. 2011). Network interdependencies regarding the formation of economic interaction structures can be quantified via stochastic actor-oriented models. Stochastic actor-oriented models are statistical parametric models for evolving networks (Ripley, Snijders et al. 2012; Snijders, Lomi et al. 2013). The technical details of this approach may be found in the appendix and in the cited works of T. A. B Snijders and his colleagues (Snijders 2001; Snijders, van de Bunt et al. 2010; Steglich, Snijders et al. 2010). This modeling approach enables us to uncover firms' preferences in selecting their suppliers.

The model assumes that actors can change their outgoing ties. Therefore, we code the observed network data for the model input such that links are directed from clients to suppliers. The models are constructed such that clients may choose their suppliers based on endogenous network characteristics (such the relationship of the supplier with other clients and suppliers) and the clients' and suppliers' performance. Furthermore the firm's performance may change depending on the structure of the supply network and the suppliers' performance. These statistical tendencies are captured by the effects in Table 2. The goal of the simulation in this study was to recreate the observed evolution of the supply networks and the revenues and determine the direction and statistical significance of these effects. Their magnitude expresses the log-odds-ratio of procuring parts from a supplier described by the effect or an improvement of performance by one step on the RPE scale.

Using methods developed by Lospinoso and Snijders (2011), we tested the goodness of fit of the model on the overall fundamental network characteristics that were not explicitly modeled by any of the included micro-effects (specifically, the degree distribution, geodesic distance distribution, and triad census). Guided by our hypotheses regarding factors influencing supply network evolution, we searched by trial and error for a model specification with an acceptable fit with the observed reality. We aimed for the simulations to reproduce the fundamental network characteristics such that the observed statistics were within their 90% confidence intervals. The fit of the models is discussed in detail in the appendix.

4. Results

4.1. Descriptive results

The 2006 and 2011 supply networks among the top 100 Japanese automobile firms are depicted in Figure 2 but network graphs of this size and density do not simply reveal their structure to a naked eye. The quantitative changes in the supply networks and the RPE scale are summarized in Table 3. While 388 supply links remained unchanged, 169 changes in the supply networks were registered. These changes comprise of 131 new created supply links and 38 severed links. The overall supply network density among these 100 largest automobile firms increased from 0.045 to 0.059 as the average number of suppliers of each firm within the sample increased from 4.5 to 5.9. Six of the top 100 firms from 2006 are not present in the 2011 data. This amount of missing values is within the limits tolerated in this modeling framework and should not impair the reliability of the results (Ripley et al. 2012). As recommended by the authors of the analytical method (Ripley et al. 2012), the missing values for their links were imputed with values of the same dyads in the previous observation. Table 2 displays values based on the raw data, whereas the metrics in Table 3 are calculated after the imputation. In terms of the RPE categories, 12 firms improved their rank, 20 firms decreased their RPE rank, and 59 remained in the same RPE category. The RPE data for nine firms is missing.

4.2. Estimation results

Table 4 presents the estimation results for Specification A and Specification B. The estimates for both alternative specifications are very similar. In the following discussion we cite the results of Specification A unless stated otherwise. The effects describing the network dynamics are in the upper part of the table and the lower part of the table describes the revenue dynamics. It is considered that the network evolution may be endogenously influenced by its own shape or by the firms' performance expressed in terms of RPE categories, which are also dynamic and their evolution is estimated simultaneously in the second part of the model.

First, we report the effects describing the endogenous network evolution in Part 1.1 of Table 4. The reciprocity effect is positively significant. This means that, controlling for other effects, bidirectional trade between pairs of firms is more common than expected by chance. In other words, a firm is more likely to procure goods or services from a firm that procures goods or services from them, *ceteris paribus*. This result reminds us again that supply networks are not linear chains characterized by a unidirectional flow of goods. The estimates of the model can be interpreted in the same manner as results of logistic regression. As explained in the appendix, the objective function quantifies the desirability of different supply management strategies (specifically the log odds of alternative supply chain configurations) and procuring goods from an existing client increases the value of the objective function by 2.351 (Table 4, 1.1.) This means that a firm that is given the chance will prefer to procure goods from a firm that procures goods from them with 10 to 1 odds as compared to otherwise equivalent alternatives (because $e^{2.351}$ is approximately 10).

Next three effects describe the tendency of actors to form triangular elements in the supply networks by preferring to form and maintain links with partners from the same cliques who have many partners in common. The first two effects are transitive triplets and three-cycles. The transitive triplets are triangular network motifs in which supplies flow from one side to the other; the three-cycles represent cliques with cyclical flows. Both effects are insignificant. Furthermore, the following negatively significant "same suppliers" effect also operates against network closure. (This effect corresponds to the "balance" effect in the Siena modeling framework.) The negative estimate of this effect implies that firms were likely to drop links to partners that procured supplies from the same partners and sought firm that were not yet accessed by their existing partners.

If firms preferred to keep suppliers from the same densely interconnected business groups with many partners in common and high levels of embeddedness (Granovetter 1985), we would expect the effects representing transitive closure (transitive triplets, three cycles, same suppliers) to be positively significant.

Although network closure effects are usually important drivers of network evolution (Ripley et. al. 2012), a significant tendency towards forming and keeping cliques among the selected automakers was not found. Despite this outcome, the goodness of fit tests show that the observed dynamics of transitive closures is represented satisfactorily by the presented model (appendix). Lack of significance of the transitive closure and three-cycles, and negative significance of the "same suppliers" implies that it was possible in this period to disconnect from firms even if they had many partners in common, and connect to otherwise unrelated suppliers in different cliques. In summary, controlling for other effects, this network does not reveal a significant endogenous tendency towards clique formation.

The next effect in Table 4, "number of 2nd-tier suppliers", is negatively significant and implies that firms preferred to abandon intermediates that provided indirect access to multiple second-tier suppliers. The more suppliers a firm has the less attractive it became as a supplier for other firms. For example, severing contract with an intermediary that provides an indirect access to 10 second-tier suppliers contributes 10*0.091 to the firm's objective function that describes the log odds of different supply chain configurations. Thus, if an assembler had to make a choice between (1) procuring supplies from an intermediate who buys parts from 10 producers or (2) procuring directly from an original producer that has no other supplier in the network; the odds ratios of taking option 2 versus option 1 would be exp(0*(-0.091)-10*(-0.091)), i.e., 2.5:1. In other words, if the two options were hypothetically equivalent in terms of all the other effects, the assembler would chose the original producer instead of the intermediate with an approximately 70% probability.

Both dismissing first-tier suppliers who broker access to many second-tier suppliers and connecting directly to second-tier suppliers (and thus turning them into first-tier suppliers) decreases the number of second-tier suppliers and hence is supported by this negatively significant effect. It should be noted that although the main transitive closure effects were not positively insignificant, creating links to second-tier suppliers may be an alternative micro-mechanism producing transitive closure, if the original link to the first-tier supplier is also preserved. However, creating a secondary path to a supplier already accessed through a broker is less likely than severing the contract with the broker for the following reasons. A new direct link to a second-tier supplier contributes through the "number of 2nd-tier suppliers" effect only 0.091 to the firm's objective function that guides its probable course of action because this link transforms the 2nd-tier supplier into a 1st-tier supplier and thus decreases the number of 2nd-tier suppliers by one. In contrast, severing the link with the broker contributes to the objective function 0.091 multiplied by the number of the broker's suppliers. Additionally, duplicate paths to the same suppliers via brokers are also discouraged by the negative "same supplier" effect.

The firms in the sample sought the most popular suppliers that had many clients, which is captured by the indegree popularity effect. The network selection model also controls for the average number of links each firm tends to create and maintain by the outdegree effect and thus, in turn, controls for the number of links in the whole network, i.e. the network density . The negative estimate is expected because most firms procure supplies from only a small fraction of firms within the sample. A procurement link becomes statistically likely only if the total log odds of a link become higher than zero by activation of other positive network effects. The inverted outdegree effect was included in the model to account for a potential non-linearity in firms' procurement activity. Although the inclusion of this effect improved the goodness of fit of the whole model, the effect itself is not statistically significant.

The model also accounts for the potential influence of firms' changing performance on their subsequent supply network management strategy, on their attractiveness as suppliers, and for the possibility that performance similarity (or dissimilarity) among two firms may influence the probability of trade between them. In the final complete model, which considers possible causal influence both from networks to revenues and from revenues to networks, none of the effects of performance of a firm's suppliers or clients on its network is significant, as shown in Part 1.2 of Table 4. Performance does not seem to drive the network evolution. In a model that does not include the effects capturing the influence of networks on revenues (not presented here), client's performance is positively significant. Thus, when the possibility of causality in both directions is not considered, it appears that good performance is followed by expanding of supply chains. However, the present modeling framework suggests that the opposite causal mechanism reconstructs the observed dynamics more faithfully. Specifically, improved performance appears to be a consequence of expanded supply chains to a wider range of first-tier firms rather than vice versa.

Now we move to the revenue dynamics (Part 2 of Table 4). As could be readily observed (Table 2, Table 3), automakers revenues per employee generally decreased in this period. The negatively significant baseline linear revenue trend captures this trend of decreasing RPE in the observed period. The quadratic effect signifies that this underlying trend is not linear but depends on the firms' current RPE. High-performance was not self-sustaining. Conversely, the performance of previously high-RPE firms was more likely to deteriorate.

The last part of the model examines the effect of supply networks on firms' performance by two alternative specifications. The first specification examines whether the number of suppliers influences revenue trends. The result is positively significant. Firms that have more suppliers tend to improve their revenues per employee over long term. The second specification tests whether the performance of the suppliers has an impact on the client's performance. This specification produces negatively significant result, suggesting that obtaining supplies from high RPE firms has a negative effect for the assembler's RPE over long term.

5. Discussion, conclusions, and implications

It is directly observable that the largest Japanese manufacturers increased the number of direct supply connections to each other within this period and thus increased the overall supply network density. However, the stochastic actor oriented modeling did not reveal a particular preference for creating and maintaining locally dense cliquish structures which would be expected if keiretsu considerations were constraining procurement strategies. Although a reciprocation of business opportunities is common, this normative micro-mechanism does not seem to generally extend beyond each client-supplier pair to larger groups of firms. The lack of significance of effects representing transitive closure effects contrasts with statistically significant tendencies towards closure uncovered by the same methods within the network of the largest Japanese firms from all industries including non-manufacturing sectors (Matous and Todo 2014). In the wake of recent scandals regarding collusion of suppliers and price fixing in the automobile industry (Shirouzu and Shiraki 2014), it is possible that assemblers are becoming increasingly active in accessing diverse cliques of suppliers to allow shifting of business if necessary and minimize the potential for collusion.

The finding of negative influence of suppliers' RPE on clients' RPE and positive influence of the number of suppliers on clients' RPE deserves attention. Suppliers may have high RPE if they do not engage in labor-intensive production by themselves and if they add high margins to the parts they are reselling. According to the former vice-executive director of Toyota, this description fits the typical procurement style via keiretsu first-tier suppliers (Shirouzu 2015). Toyota, and other major Japanese assemblers that followed the Toyota way, traditionally dealt only with a small number of permanent first-tier suppliers and expanded production only through the first-tier suppliers by letting them procure higher volumes of materials from other manufacturers and resell them to Toyota (Wada 1992). Although such keiretsu arrangements have been for long been considered the source of the high competitiveness of the Japanese automobile industry, the recent data do not support this view anymore. The high price margin of intermediates was acceptable to assemblers because it helped to assure the quality of the products (Aoki 1990). Under the present conditions, however, the model results suggest that (1) Japanese car makers may be moving away from this strategy by bypassing the intermediaries, reaching across network cliques, and expanding the number of their direct suppliers; and that (2) this move is positive for the carmakers performance possibly because it reduces waste within the supply chains. Furthermore, this strategy may be profitable because dealing directly with otherwise disconnected partners, particularly with lower-revenue partners, may be advantageous in terms of bargaining power. Such supply chain management changes have possibly become also technically easier to implement as modularization, which allows direct substitution of parts from different suppliers, has become prevalent in the automobile industry (Corswant and Fredriksson 2002).

For companies that have not yet embarked upon this route of disintermediation and supply chain diversification, it may be recommendable to explore the opportunities. It is possible that this trend will also come to other industries as they become more exposed to global competition and shift their attention towards more price-conscious emerging market customers. Such shifts in supply chain management trends may also produce some losers and be companied by some challenges. Whereas disintermediation decreases the number of vertical steps in the supply chains at which supplies may be discontinued by internal and external shocks, in the new fluid environment of constantly reconfiguring production networks, quality control and safety assurance may become more challenging. This may prove particularly demanding for Japanese automakers with extremely slim procurement departments.

Our finding that car manufacturers seek certain hub suppliers across keiretsu boundaries resonates with concerns voiced by a white paper by the Japanese Ministry of Trade, Economy, and Industry. (METI 2011). This white paper, which was published soon after the Great East Japan Earthquake in 2011 and incorporated data from opinion surveys of Japanese enterprises, reported that manufacturing procurement in Japan has acquired a “diamond structure” characterized by a concentration of supply links on certain key original producers of parts and materials. The implication of the new macro-structure is that if such suppliers suffer damage, negative temporary shocks can now propagate through the whole supply networks regardless keiretsu boundaries.

There may be some role for public institutions to assure that the reconfiguration of the previously stable and save (even if not most efficient) production networks is not accompanied by new safety risks. Furthermore, the role of trading companies within the domestic market may decrease in a highly competitive environment characterized by cost-cutting in supply procurement and disintermediation. Rather than facilitating access to Japanese suppliers upstream, a possible new role for general trading companies may be to support access to customers on the frontier of the new emerging markets downstream.

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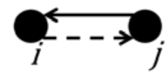
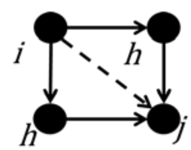
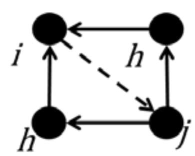
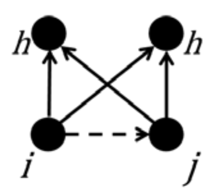
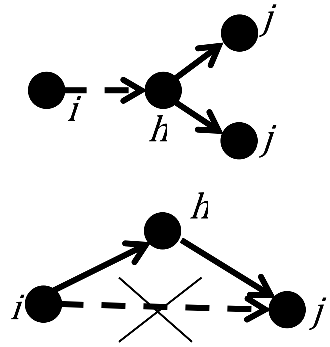
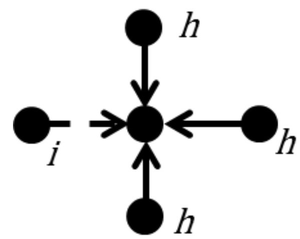
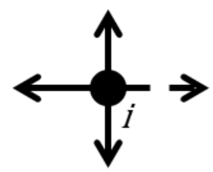
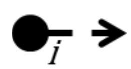
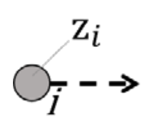
Tables

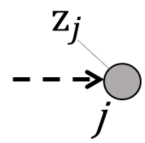
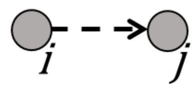
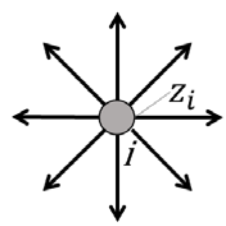
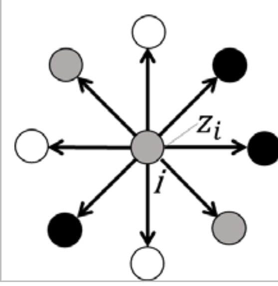
Table 1 – The revenues and the number of employees of the hundred largest firms in the Japanese automobile manufacturing sector

	Min	Median	Mean	Max	NA
Revenues in 2006 [‘000 Yen]	$7.39*10^6$	$7.27*10^7$	$3.88*10^8$	$9.22*10^9$	1
Revenues in 2011 [‘000 Yen]	$5.00*10^6$	$8.10*10^7$	$4.02*10^8$	$8.24*10^9$	8
Employees in 2006	800	1395	4316	65994	0
Employees in 2011	630	1580	4862	69310	7
RPE in 2006 [‘000yen/person]	7393	52390	61220	143900	1
RPE in 2011 [‘000yen/person]	6098	48960	57980	20560	8
logRPE 2006	8.908	10.87	10.88	11.88	1
logRPE 2011	8.716	10.8	10.81	12.23	8
Number of suppliers in 2006	0	1	4.5	45	
Number of suppliers in 2011	0	2	5.2	41	

Table 2 - Formulas for $s_{ki}(x)$ selection effects in network x for ego i and alters j, other actors h, and actors' attributes v. In the actor-oriented modeling framework, network links are directed from clients who make the procurement decisions to the suppliers that they select. Dashed arrows signify trading relationships that are likely to be created and maintained if the effect is positive.

Effect name (Additional description)		Mathematical formula	Graphical representation
Network dynamics			
Endogenous trade network interdependencies Network → network			
Reciprocity (Favor firms that buy something from our firm.)		$\sum_j x_{ij} x_{ji}$	
Preference for firms with partners in common (i.e., firms within the same trading group)	Transitive triplets (Hierarchical cliques)	$\sum_{j,h} x_{ij} x_{jh} x_{hi}$	
	Three-cycles (Non-hierarchical cliques)	$\sum_{j,h} x_{ji} x_{ih} x_{jh}$	
	Common suppliers (Connect to firms that use the same suppliers)	$\sum_j x_{ij} \sum_{\substack{h \\ h \neq i,j}} (b_0 x - \lvert x_{ih} - x_{jh} \rvert)$	

Number of 2nd-tier suppliers (Connect to multiple primary suppliers through intermediaries)	$\#[\mathrm{j} \mid x_{ij} = 0, max(x_{ih}x_{hj}) > 0]$	
Indegree popularity (Seek the most popular suppliers)	$\sum_j x_{ij} \sum_h x_{hj}$	
Outdegree (Control for network density)	$\sum_j x_{ij}$	
Inverted outdegree (Diminishing marginal tendency toward increasing the number of suppliers)	$\frac{1}{\sum_j x_{ij} + 1}$	
Effects of firms' performance z on supply network structures Revenues → network		
Client's performance (High-performing firms connecting to more suppliers)	$\sum_j x_{ij} z_i$	

Supplier's performance (Selecting high-performing firms as suppliers)	$\sum_j x_{ij} z_j$	
Similarity of performance (Preference for firms with similar performance)	$\sum_j x_{ij}(sim_{ij}^z - \overline{sim^z})$	
Revenue dynamics		
Linear revenue trend (Baseline revenue trend)	z_i	
Revenues → revenues		
Quadratic revenue trend (The effect of current revenues on the future revenue trend)	z_i^2	
Network → revenues		
Specification A: The effect of the number of suppliers on the future revenue trend	$z_i \sum_j x_{ij}$	
Specification B: The effect of the suppliers' revenues on the revenue trend	$\sum_j x_{ij}(sim_{ij}^z - \overline{sim^z})$	

Note: x_{ij} = 1 if there is a directed tie from i to j and 0 otherwise

[b] $\overline{sim^z}$ is the mean of all similarity scores, which are defined as $sim_{ij}^z = \frac{\Delta - |z_i - z_j|}{\Delta}$ with $\Delta = max|z_i - z_j|$

Table 3 – Descriptive results: changes of suppliers between 2006 and 2011; distribution of firms by revenue categories; and revenue dynamics.

	Count
Network dynamics	
Whole network density in 2006	0.045
Whole network density in 2011*	0.059
Average number of suppliers in 2006	4.50
Average number of suppliers in 2011*	5.88
Preserved supply relationship	388
New suppliers	131
Abandoned suppliers	38
Total of changes	169
Jaccard index	0.697
Missing links in 2006	0%
Missing links in 2011	11.7%
Revenue categories	
Low revenue firms in 2006 (logRPE<10.5)	21
Middle revenue firms in 2006 (10.5<=logRPE<11.5)	62
High revenue firms in 2006 (logRPE>=11.5)	16
NA in 2006	1
Low revenue firms in 2011 (logRPE<10.5)	25
Middle revenue firms in 2011 (10.5<=logRPE<11.5)	55
High revenue firms in 2011 (logRPE>=11.5)	12
NA in 2011	8

* The network metrics in this table are calculated after imputation of 2006 values for the 11.7% of missing values in 2011.

Table 4– Stochastic actor- oriented model: the network dynamics component of the model estimates the log odds of procuring parts between a client and supplier embedded in network structures and characterized by performance described by the estimated effects; the revenue dynamics component of the model estimates the log odds of increasing productivity by one step on the RPE scale

Hypothesis Effect name	Specification A Parameter estimate	Specification A Standard error	Specification B Parameter estimate	Specification B Standard error
1. Network dynamics				
1.1. Endogenous trade network interdependencies				
Network → network				
Reciprocity	2.351*	0.293	2.331*	0.277
Transitive triplets	0.030	0.049	0.045	0.051
Three-cycles	0.139	0.123	0.135	0.122
Same suppliers	-0.041*	0.018	-0.051*	0.025
Number of 2nd-tier suppliers	-0.091*	0.025	-0.102*	0.034
Indegree popularity	0.119*	0.021	0.119*	0.021
Outdegree	-2.537*	0.348	-2.528*	0.367
Inverted outdegree	1.258	1.983	1.329	2.417
1.2. Effects of firms' performance z on supply network structures				
Revenues → network				
Client's RPE	1.464	0.989	1.305	0.825
Supplier's RPE	0.180	0.254	0.157	0.232
Similarity in RPE	0.652	0.682	0.691	0.543
2. Revenue dynamics				
Baseline revenue trend	-0.901*	0.434	-0.387	0.299
Revenues → revenues				
Quadratic revenue trend	-1.491*	0.532	-1.478*	0.471
Network → revenues				
Specification A: The effect of the number of suppliers on the future revenue trend	0.113*	0.049		
Specification B: The effect of the suppliers' revenues on the client's revenue trend			-0.217*	0.117

* p<0.1

Figures

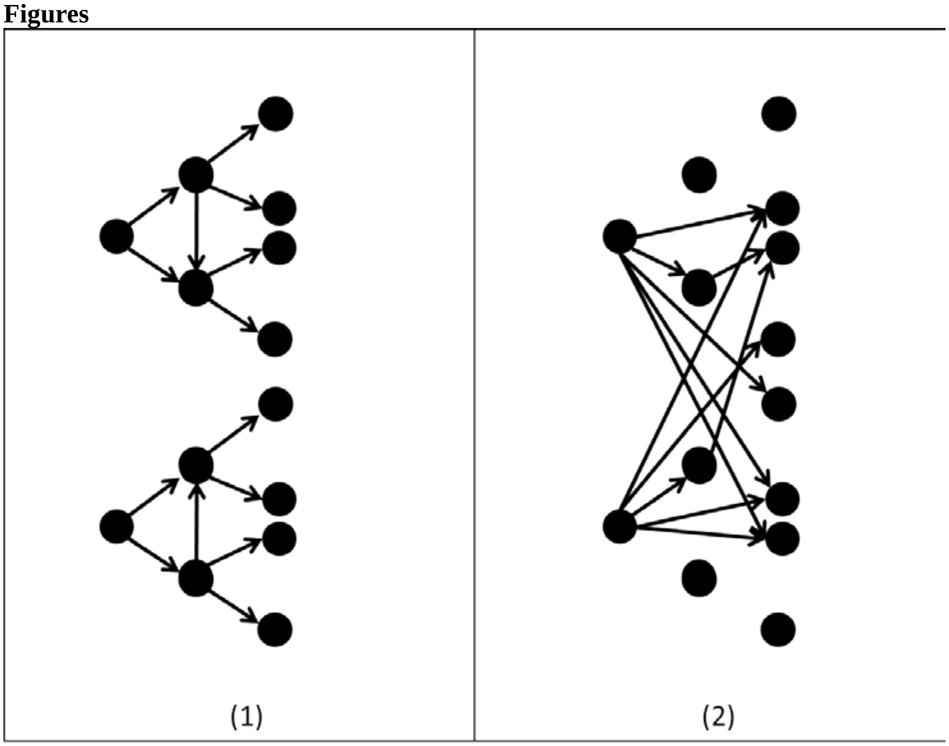


Figure 1 – (1) Network elements of traditional keiretsu structures and (2) a hypothetical post-keiretsu supply network. Arrows point from clients to suppliers

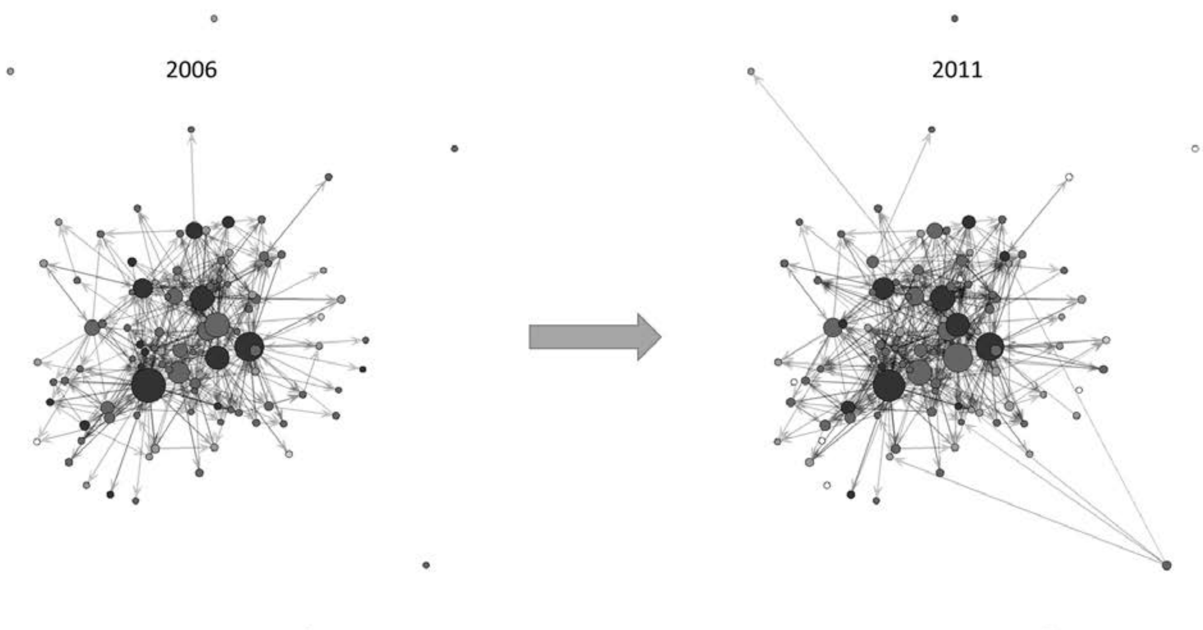


Figure 2 – the supply networks in the beginning and the end of the observed period. The node shade depicts the revenue per employee category (high RPE nodes are darker); the nodes size depicts the number of suppliers; arrows depict flow of finance from clients to suppliers

Appendix

This appendix explains the method of stochastic actor-based modeling for network evolution. The model conditions on the first observation and tests hypothetical drivers of the evolution of the network and the revenues. The network evolution is treated as a continuous-time Markov chain of single trading link changes between observations.

Between the observations, each firm may receive one or more opportunities in a random order to change its suppliers represented by its outgoing ties and it may also move up or down on the RPE scale. The model includes ‘rate effects’ that regulates how often actors receive an opportunity to modify their outgoing ties and the frequency of changes in RPE. These rate effects depend on the number of observed changes. Only one actor acts at a time, and coordination is not allowed.

Each firm chooses its suppliers according to an objective function in which the desirability of each supply network configuration x is expressed from the viewpoint of actor I, as in generalized linear models, as a combination of hypothetically relevant network features $f_i(\beta, x) = \sum_k \beta_k \, s_{ki}(x)$. A random component with a standard Gumbel distribution is added to the evaluation function. This procedure is included to respect the stochastic character of network evolution, which is a result of influences that are unrepresented by nodal or dyadic variables and of measurement errors. Thus, the actor does not necessarily choose the state with the highest utility, but such a choice is most likely. When a firm receives an opportunity to change its suppliers, the options are to create one new tie, delete one existing tie, or do nothing. An analogic but separate function is used to express the likelihood of a decrease or a decrease in RPE.

Each effect s_{ki} in the model corresponds to possible reasons why a change in firm’s network or revenues might occur. These network evolution effects describe the firm’s supply chain management tendencies and the revenue evolution effects describe possible effects of the supply network structure on revenues. The explanations and mathematical formulas of effects s_{ki} are presented in Table 2.

The goal of the simulation is to estimate the relative weights β_k for the statistics s_{ki}. Parameter estimates can be used to compare how attractive are various supply chain configurations and likely are any changes in revenues while controlling for other exogenous and endogenous effects. The signs of β_k indicate the likely directions of network or revenue change, and their relative magnitudes can be interpreted similarly to parameters of multinomial logistic regression models in terms of the log-probabilities of changes among which the actors can choose.

The estimation was executed in SIENA package version 4 in R (Ripley, Snijders et al. 2012). The method of moments, which depends on thousands of iterative computer simulations of the change process (Snijders 2001), is used to estimate the parameters β_k that enable the reproduction of trading network evolution between 2011 and 2012. There is one target statistic for each estimated effect (for example, the number of ties in the network corresponds to the outdegree effect, the number of reciprocated ties corresponds to the reciprocity effect, and the amount of change in network corresponds to the rate function). The presented models all converged with T-ratios, quantifying the deviations between the simulated and the observed values of the target statistics, between -0.1 and 0.1, which indicates an excellent model convergence (Ripley, Snijders et al. 2012). In the final stage of the simulation, the standard errors of the estimated parameters are computed by the finite difference method, based on the sensitivity of the target statistics to β_k.

The diagrams below indicate the goodness of fit of the three presented models in terms of indegree distribution, outdegree distribution, geodesic distance distribution, and triadic census using methods developed by Lospinoso and Snijders (2011).

The violin plots (Hintze and Nelson 1998) represent the kernel density distribution of the statistic and the red lines depict the cumulative distribution of the observed values. The violins are not smooth for less frequent higher degree nodes because the density plots approximate distribution of a small number of discretely distributed values (Ripley, Snijders et al. 2013).

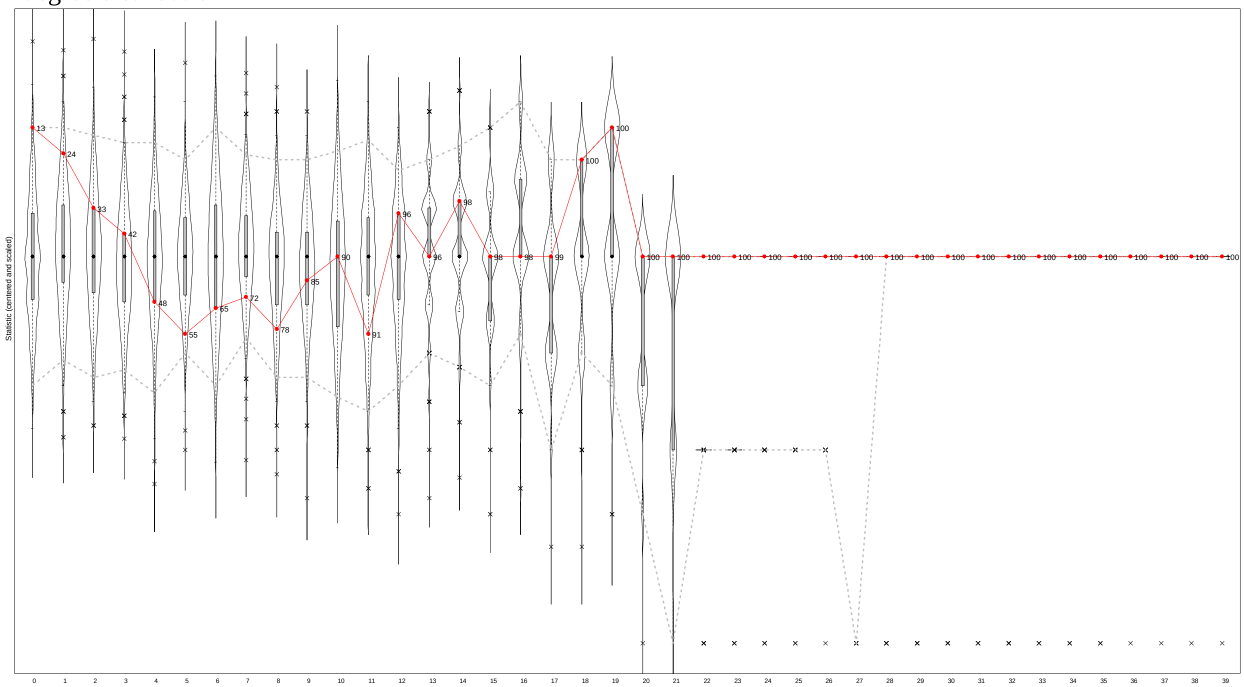
Because the values for different statistics within each plot vary widely, each violin is scaled and centered to maximize the visibility of the plot. The dotted grey lines designate a point-wise 90%relative frequency band for the simulated data. The fit is considered acceptable if the observed values (red lines) fall within this region. However, the goal is not necessarily to match the model exactly on every single statistic which can be highly irregular. Such approach would require over-fitting the model to all incidental lone observations or errors in the data and necessitate addition of theoretically irrelevant effects.

Standard labeling is used for the classes of the triad census (Wasserman and Faust 1994).

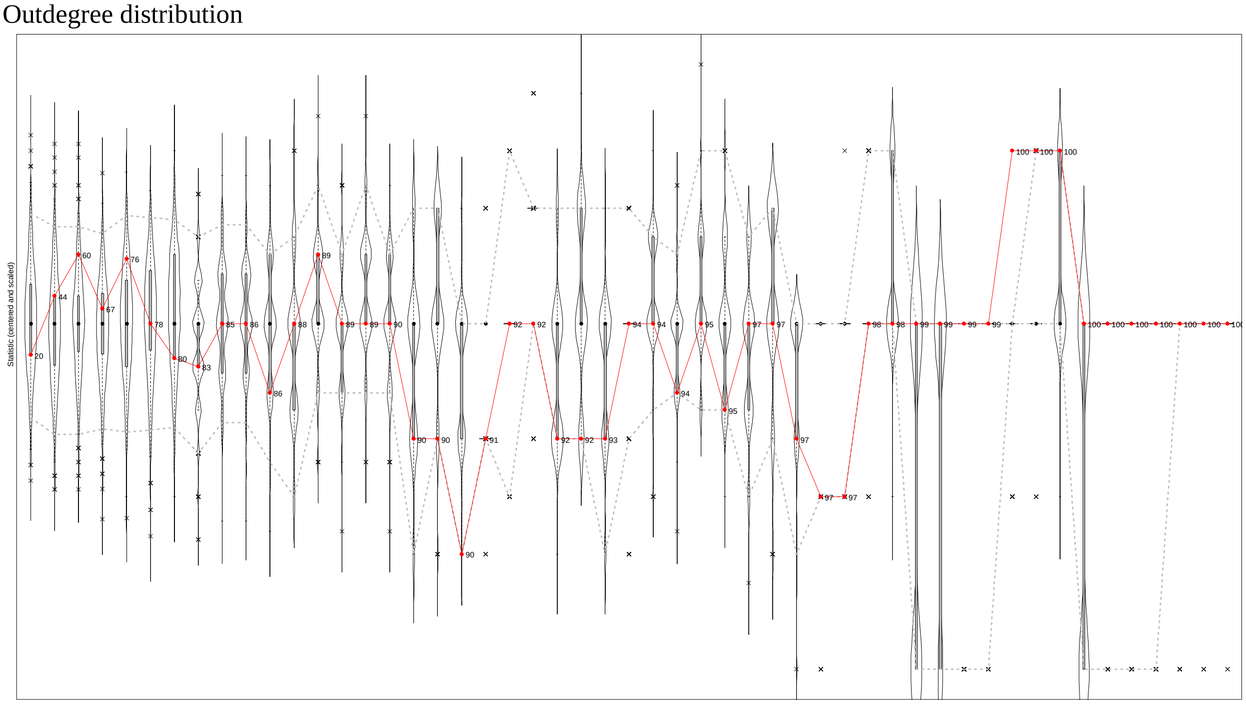
Goodness of Fit

(Only the goodness of fit of Specification A is presented to save space because the diagrams are almost identical for Specification B.)

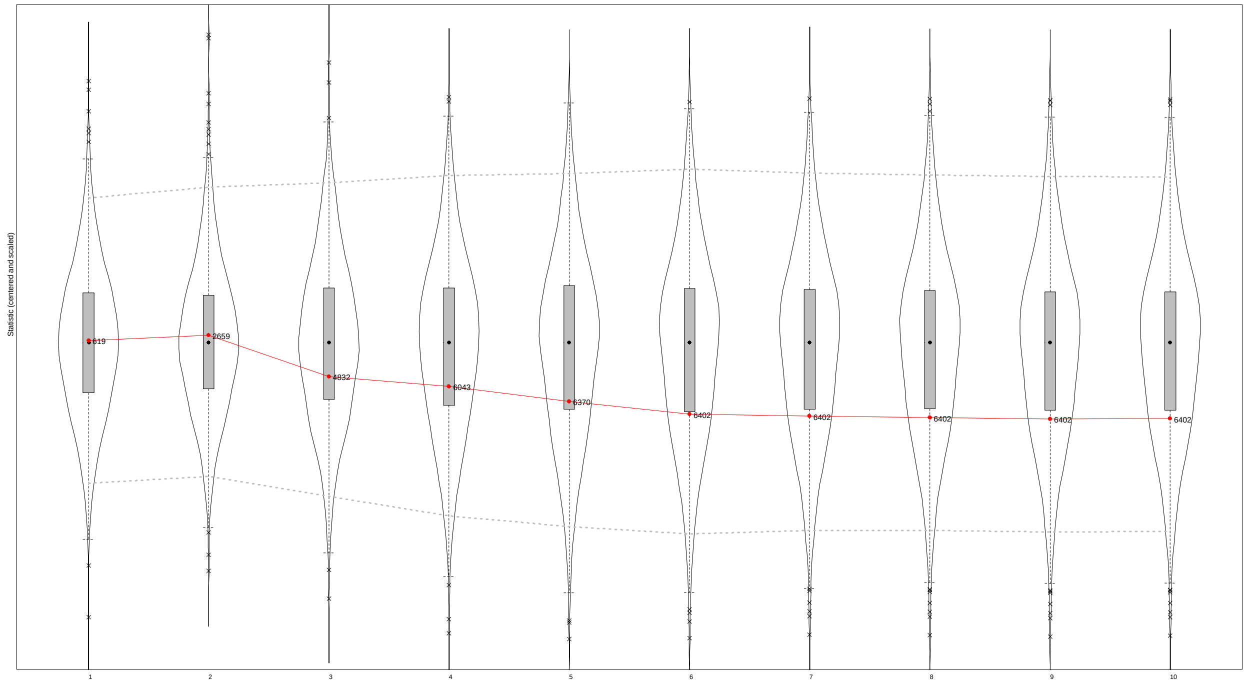
Indegree distribution



Outdegree distribution



Geodesic distribution



Triadic census