Dynamics of Inter-firm interactions in Indian Automotive Industry: A Social Network Perspective

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Abstract

This paper studies the vertical relational structure of automotive and auto component firms in the Indian automotive supply chain where a clear 'unequal balance of power' is observed. This is done by combining the theories of network and systemic idea of innovation. We uncover the hidden relational structure of the automotive and auto component firms and find that the industry network shows some prominent scale-free structural properties indicating the existence of a typical dependence and dominance structure with complex dynamical behaviour. We also draw on the innovation and sustainability characteristics of the firms' network and their inclination towards vulnerability and some related policy implications.

Key Words: Automotive supply chain, scale-free network, industry evolution, innovation, Indian automotive industry

[1] This paper benefited immensely from the comments of Bart Verspagen, Robin Cowan, and the late Paul Geroski. The scientific responsibility is, however, assumed by the author.

1. Introduction

Fast-paced technology and demand conditions, together with the compulsions of ever greater integration of the Indian economy with the global network, have placed the Indian automotive industry at a crossroads. Noteworthy changes have occurred since liberalization in 1991. However, although there is marked improvement in total factor productivity growth (Iyer, et al., 2006) and average labour productivity (Das and Rao, 2004), the rate of new technology diffusion is still far from reaching its optimum (Parhi, 2006). While several studies have been carried out on growth and performance in the automotive industry, relatively less research has been conducted to explain the underlying relationship structure of firms which potentially lies behind such aggregate/macroeconomic effects as aptly underlined in the innovation literature. An understanding of the organizational/relational structure of the firms in the automotive industry is thus paramount to the understanding of aggregate growth dynamics at the industry level.

Uncovering the true interactive pattern among firms in the automotive industry (broadly between auto component manufacturers or suppliers and automotive or buyer firms) may reveal hidden dynamics, namely, the existing dependence and dominance structure of firms and the evolving dynamical changes based on the strength of interactions. Such patterns could provide ample knowledge about the innovative capability of firms and their possible future evolution and corresponding macroeconomic effects. This may also help explain the aggregate growth dynamics. In view of the myriad implications of the interactive behaviour of firms, this paper aims to provide a comprehensive analysis of the dynamics of inter-firm interactions in the Indian automotive industry1) and investigate their influence on industry structure and performance by blending the systemic notion of innovation with the emerging theory of networks. To the knowledge of the author, despite voluminous research, there is no previous study on the Indian automotive industry to date, which attempts to model the network characteristics of firms for underlining the evolution and importance of this industry in the Indian economy. The broad purpose of this paper is to undertake such task.

Indeed, the artistry of innovation in organizations is evolving rapidly in sync with the changing time and increasing complex needs of the socio-economic and business environments. Accordingly, the path and process of innovation, far from being linear and atomistic, has become exceedingly complex and interactive. This recognition, originating mainly from the systemic perspective of innovation (Lundvall, 1992; Edquist, 1997), rightly puts interactions among firms and their specificities concerning the patterns of interaction in the system as the core of innovation. This interaction perspective is also prominent in the research tradition of business management where it shows that innovation is the outcome of the buyers' and suppliers' sustained cooperation over time (Robertson and Gatignon, 1998; Sivadas and Dwyer, 2000).

Arguably, buyers-suppliers[2] relations grow and mature within the network (supply chain). This is because the interactions are nurtured by the network characteristics; in return, these interactions govern the evolution of the network itself. Hence, it is imperative to understand in what ways the network characteristics shape the interactions of the actors (buyers and suppliers) and in turn get shaped by them. Lately, the interactive nature of buyer-supplier relations has provided impetus to extensive research on how the relation drives innovation in the supply chain. Banking upon some well-established theories (e.g., systems of innovation, transaction cost, political economy, and social exchange) which formulate the core of buyer-supplier dynamics, the 'relations' have been extensively tested empirically, guided mainly by the industrial marketing literature. For instance, the success of 'Japanese (lean) production' in the automotive industry is accrued to the 'strong' buyer-supplier relationship (Sako, 1992), indicating profundity of the power of co-operation/ interaction.

[2] For fluidity of expression, we use buyer-supplier and customer-supplier interchangeably in the text.

Although the extant literature is effusive in justifying the 'interactive' nature of the relation, specifically why the interaction among buyers and suppliers is key to successful innovation, it seems to be equally evasive in specifying how the pattern and strength of interactions accelerate innovation. Clearly, an underlying mechanism is missing. In our view, integrating the features of the 'interaction space' or 'network' into the framework of buyer-supplier relations would provide a distinct view of the dynamics of innovation in the supply chain[3]. The topological space of the inter-firm network consists of nodes (in our case, firms) and edges (linkages among firms). Depending on the typology of nodes, the topology of interactions provides meaningful directions about the nature and complexities of the system. Following this systemic notion, where every node (firm) is a part of the broad system or network, the analysis of inter-firm linkages would go a long way in unravelling the innovation process at the firm level. Indeed, the research devoted recently to the understanding of the organization and the dynamics of industries using the network theory (for instance, Bonaccorsi and Giuri, 2001 etc.) speaks volumes of its veritable importance in this field.

The usefulness of network analysis in the study of growth dynamics in the automotive industry is motivated by several important reasons. A quick survey of the study of the automotive industry would reveal that most of the analyses are based on the econometric point of view, estimating productivity growth and technical efficiency over some period of time. Any macroeconomic or firm level study over a specified period of time indicates only aggregate behaviour. However, what generates such aggregate outcomes still remains a question. Taking the case of the Indian automotive industry, we know that it has gone through a paradigmatic change and the recent trends show that the industry's growth is in the upswing, attracting many global players into the country and facing ever new competitive challenges. The striking development feature of the automotive industry is not instantaneous. Rather, it is grounded in continuous and conscious policy decision-making over the years, side by side with the changing relations within the industry structure, resulting in the current growth momentum.

The interaction pattern of the automotive and auto component firms and their evolution over the years are vital in discovering the secret behind observed growth dynamics. However, does the relational structure which defined/generated the aggregate dynamics show some definite pattern? Is it subject to random shocks and is it susceptible to targeted attack from within the system? Can a small change in the pattern of the relational structure change aggregate outcome to a significant extent? These are some of the intriguing questions that we intend to tackle in this paper. By exploiting the development of the complex network theory in the study of the interaction pattern of the Indian automotive and auto component firms, we report many new features of the industry and their development/implications for further growth, which to the knowledge of the author, have not been explicated so far in the literature.

The main objective of this paper is to examine the topological structure of the buyer-supplier network in the Indian automotive industry by scrutinizing its statistical properties and discussing its significance in the organizational structure, conduct, and performance of the industry. Our contribution lies in the emphasis on the vertical instead of horizontal relations between individual firms in the supply chain[4] where an 'unequal balance of power' (in the sense that the weight of interactions is governed by one side) is observed. In the case of the supplier-customer network (in the automotive industry), the power balance is usually found to rest on the customers or the automotive firms (Parhi, 2006). Presuming that the implications of the interactions between these types of actors would be different from the one where there is equal power balance in the network, the analysis of the supplier-customer network in the Indian Automotive industry is intended to shed light on the organization and possible evolution of this industry. Moreover, the topological

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[3] In fact, in another context (purely from the managerial perspective), a similar line of argument has been put forth (Lazzarini et al., 2001).

[4] To the knowledge of the author, Bonaccorsi and Giuri (2001) is the only recent paper directly investigating the vertical relation network (particularly, supplier-customer networks) in order to study the evolution of industries.

properties of buyer-supplier relations are likely to unravel the various social dimensions of the economic transactions taking place between firms.

The rest of the paper is organized as follows: Section 2 briefly discusses the significance of supplier-customer networks and studies how the relations have evolved in the Indian automotive industry; Section 3 describes the methodological framework of the paper; and Section 4 discusses the empirical results. Section 5 concludes with the possible implications and directions for further analysis.

2. Evolution and Importance of Supplier-customer Networks

2.1 The Importance of Buyer-supplier Network and Industry Organization

The fact that network represents 'a dominant organizing principle for explaining the functioning of a system' has encouraged researchers in various social disciplines to use 'network theorization' as potential reasons behind the complex behaviour and evolution of various systems. Particularly, its popularity has grown immensely in the study of innovation and technological change where the synergetic effect of the firms' 'connectedness' is shown to be a prime mover of innovation.

Among many forms of inter-firm networks in the corporate world, supplier- customer networks dominate the landscape of organizational forms in manufacturing because of two principal reasons. First, the manner by which suppliers choose their clients or vice versa is veritably crucial for the market success of the firms and the success of businesses at large. Another reason is that users and suppliers represent the two important agents in any production system, regulating the production (supply) side and the demand side uncertainties. The synergies that result from the network between them thus control the overall uncertainties in the production system to a large extent. Hence, the stronger the network between the users and the suppliers, the lesser would be the uncertainty in the market. The networks between customers and suppliers are also quite meaningful as they capture the vertical organization structure of the industry. They have become rampant with the advent of complex manufacturing products where vertical disintegration offers many advantages such as greater corporate efficiency and profitability.

The idea of vertical disintegration is most vivid in the case of automotive industry. There is considerable supplier-buyer interdependence in the automotive industry, as components need to be tailor-made, depending on the type and design of vehicles. Hence, components and vehicle segments are inextricably linked. Recently, the trends in the global automotive industry have redefined the importance of component manufacturers vis-à-vis the automotive manufacturers. The already existing excess capacity has led to intense competition among major automotive producers and has forced them to curtail manufacturing costs through tierisation[5]. The latter entails a greater interdependence between the levels of the industry. With the industry bending more towards systems' assembly, components manufacturers have increasingly been called upon to be competent. With the efficiency of vehicle production crucially dependent on the supplier base, the supplier-buyer relations in the automotive industry are also evolving in even more complex ways.

The role of customers is very crucial in the evolution of the auto component industry. In fact, the dynamical changes taking place in the auto component industry are entirely governed by customers, i.e., the automotive firms[6]. An analysis of the supplier-customer network, therefore, would help in examining the way the industry is organized and to understand its current as well as future dynamics. Moreover, the technological underpinnings of the auto component industry can also be assessed by looking at the structure of this network and by reviewing its various features.

[5] The process of shifting part of the assembly, i.e., sourcing assemblies or systems instead of individual components, down the supply chain is called tierisation.
[6] The term automotive is used in a broader sense including both the vehicle manufacturers as well as the tier-1 firms in the industry.

2.2 Changing Facets of Supplier-customer Linkages

The Indian automotive industry is a vital sector of the economy, accounting for nearly four percent of the GDP. Though the industry is nearly six decades old, notable changes in its structure and performance only began in the early 1980s with the onset of economic reforms. Until then, only three manufacturers (in the car segment), namely, Hindustan Motors, Premier Automobiles, and Standard Motors dominated the industry. Due to low volumes of sales and government protection, obsolete technologies prevailed and the Indian industry was dissociated from the development in global industry. The industry witnessed significant restructuring in 1982 with the establishment of the Maruti Udyog Limited (MUL) in collaboration with Suzuki Motors of Japan. The inflow of capital and technology from Japan brought defining changes in the performance of the industry. Within a decade, the industry metamorphosed into a relatively high-growth and dynamic one marking about a 17-fold jump in car production by the year 2000 (D'Costa, 2004). Following the success of MUL, other global players entered the fray, raising not only India's output substantially but also diversifying the industry with qualitatively new products.

The auto component industry had also started out in a small way in the 1940s, supplying parts to Hindustan Motors and Premier Automobiles, but set off for a higher growth path with the advent of Tata Engineering and Locomotive Company (TELCO)[7] in the 1950s (Kathuria, 1996). With TELCO, the arrival of other indigenous manufacturers, viz., Bajaj and Mahindra and Mahindra in the 1950s, also prompted the component firms to experience a steady growth spurt. The protectionist and inward oriented policies of the government, such as the reservation of certain component production by the small-scale sector and the indigenisation/local content requirements, had further added to the proliferation of the component suppliers.

Dynamism of the component firms received a big push with the foreign collaborations in the vehicle sector in the 1980s and the phased manufacturing programme. The entry of Maruti Udyog Limited (MUL) in 1982 expanded the overall demand for passenger cars in India, leading to the growth of the industry at a CAGR of approximately twenty-five percent between 1984 and 1990. The expansion of car manufacturing, in turn, encouraged the development of the automobile component firms and emphasized the localization of components and other input materials through collaborative efforts with vendors for the development of automobile components. This actually germinated the era of greater buyer-supplier co-operation in the industry.

The mode of operation and strategies of MUL with regard to its vendors contributed to the growth potential of the Indian auto component firms. MUL follows the Japanese style of operation where the company works very closely with its vendor base. In some cases, the vendors were exclusive suppliers to MUL. The production systems of its vendors were generally aligned to the company's need for a reliable and timely supply of components that met strict quality requirements. Thus, the localization strategies (e.g., vendor participation) and exacting quality standards of MUL not only created a strong component base but also promoted higher levels of local components manufacturing that helped in strengthening the industry over time.

In the 1990s, India de-licensed the passenger car industry and overseas entities were permitted (to own up to 51% of the equity of such joint ventures until 1995 and more than 51% after 1995) to set up automobile manufacturing facilities in India through joint ventures with Indian companies. As a result, manufacturers such as General Motors, Ford, Daimler-Chrysler, Peugeot, Fiat, and Daewoo Motors entered the passenger car and utility vehicles market in India. Most of the new car manufacturers introduced cars in the mid or large car segments. Though MUL has remained as the major customer for component firms in the passenger car segment, new global entrants have been consistently gaining their market share. Besides the passenger car segment, other segments (e.g.,

[7] TELCO is the largest indigenous conglomerate in the Indian automotive industry. Known widely as Tata Motors, the company produces a wide range of Commercial Vehicles, Passenger Cars, and Multi-Utility Vehicles.

tractors, light and heavy commercial vehicles, multi-utility vehicles as well as two-three wheelers) in the automotive industry have also shown a steady growth, thus raising the demand for components and paving the way for the greater role of local suppliers.

Table 1: Co-evolution of Automotive and Auto component Industry

Period	No. of firms		Output (in '000 rupees: 1980-81 prices)		Avg. labour productivity	
	Auto-component	Automotive	Auto-component	Automotive	Auto-component	Automotive
1977-84	213	102	571	5020	1.10	1.27
1985-91	265	108	662	7930	1.57	1.99
1992-99	346	126	1202	11905	3.08	5.45

Source: Own compilation from Das and Rao (2004).

A crude snapshot of how auto-component and automotive industry evolved over time is presented in Table 1. In the pre-liberalisation period, the average number of auto-component and automotive firms were 213 and 102 respectively. With partial decontrol, the number of firms grew and after the liberalisation took full effect in 1991, the average number of firms increased to 346 and 126 respectively for auto-component and automotive firms. In two decades, the growth of the average firm size in the auto-component industry is approximately 62% while the automotive firms grew by 23.5%. Moreover, remarkable changes were observed for auto-component industry growth in the pre-liberalisation and post-liberalisation periods (24% during 1977-91 and 30% during 1985-99). Not only the number of firms increased in the two sectors, but also the average productivity also saw a rising trend. For instance as shown by Das and Rao (2004), average labour productivity shot up from 1.10 to 3.08 for auto-component and from 1.27 to 5.45 for the automotive industry. The evidences provide preliminary idea about the positive co-evolution and growth of buyer and supplier firms in the Indian automotive industry in the last three decades.

Thriving upon the advantages of liberalisation, the automotive industry and the component sectors have experienced a clear transition from inward orientation and sluggish growth to a more global and a vibrant industry in recent years. The transition was also led partly by the growing complexity of products, and rapid changes in technologies and the competitive pressures in world automotive industry. While the stiff price competition in the final product market has made the user firms (automotive firms) press for high quality products from their suppliers, the openness has exposed the suppliers to a greater competition from firms both within and outside India.

Moreover, with the gradual internationalization of the automotive industry, component manufacturers also faced intense competition outside, and their response was to upgrade both their technological level and quality standards. The supply chain, in turn, has undergone a major transformation (Sutton, 2004). These developments are constantly affecting firms in a complex way and consequently the relation between suppliers and their buyers has been stacked to a different order. Given the complexities of such supplier-customer relations, an analysis of their network and its characteristics is warranted. A brief description of the methodological outline of networks is presented next before discussing the results.

3. Network Structure and Explanation of Aggregate Dynamics

3.1. Structural Properties of Networks

We introduce below the notion of networks the indicators of which are drawn from social network analysis contributions and adapted for the analysis of vertically related industries (Wassermann and Faust, 1994; Scott, 1991).

A network (G) is usually represented as a graph with a number of points defined as vertices or nodes (n) and lines joining them defined as edges (l). Comprising of total N nodes and L edges, the network can be defined over a pair $G = (V, E)$ where the sets are $V : V = \{1,...,N\}$ and $E : E = \{1,...,L\}$. Depending on whether lines joining the nodes are directed or undirected, there could be directed or undirected networks. To understand the real world complex networks, three major characteristics have been identified in the literature (Albert and Barabási, 2002; Newman, 2003).

The first characteristic showing the structure of a network is the degree of a vertex, denoted by k_i, and is defined as the number of ties that the given vertex has (Freeman, 1979). The mean degree of the vertex is the average degree of all the vertices of the network:

$$\bar{k} = \frac{\sum_{i=1}^{N} k_i}{N} \qquad (1)$$

and signifies the centrality of a network. A higher $\bar{k}$ would demonstrate a greater centralisation and vice versa. In case of a directed network, a distinction is made between 'in degree', $k_{in}(i)$, of a node and its 'out degree', $k_{out}(i)$. While $k_{in}(i)$ denotes the number of ties that i receives from others, $k_{out}(i)$ refers to the number of ties going from i.

Another salient and frequently invoked network characteristic is the average path length (geodesic) between two nodes. Intuitively average path length represents "closeness" in a network. To define the characteristic path length some preliminary definitions are needed. A "path" is a sequence of distinct, connected nodes in a network, and the "geodesic" between nodes i and j is the shortest path between them, measured by the number of lines traversed to go from i to j. The "geodesic distance" $d(i, j)$ between nodes i and j is the length of that shortest path, again measured by the number of lines traversed. The average distance from a specific node i to all other nodes in the network is given as $d(i) = \frac{1}{N-1}\sum_{j=1}^{N} d(i, j)$. The characteristic path length of the network $(\bar{L})$ is then defined as the average of the over all the nodes in the network, i.e.,

$$\bar{L} = \frac{1}{N}\sum_{i=1}^{N} d(i) \qquad (2)$$

The third characteristic of the structure of the network can be depicted by the 'clustering coefficient', which measures the tendency of the nodes to cluster in interconnected modules or regions. For any individual member of the network, clustering is defined as the density of the network consisting of those nodes to which this particular member is directly connected. The overall network clustering coefficient is the average of the same for all nodes, either weighted or non-weighted by the nodal degrees. Mathematically it can be represented as follows. Let vertex i

be connected to k_i adjacent nodes. If the actual number of edges between the k_i neighbors is l_i, then the clustering coefficient C_i of the vertex i is the fraction $C_i = \frac{2l_i}{k_i(k_i - 1)}$. The clustering coefficient of the whole network is then given by the average over all vertices i.e.,

$$\overline{C} = \frac{1}{N}\sum_{i=1}^{N} C_i \qquad (3)$$

Regular networks, where all the degrees of nodes are equal (such as circles or fully connected graphs), have been traditionally employed in modelling physical systems. But many 'real-world' social, biological and technological networks appear more random than regular (Albert and Barabási, 2002; Newman, 2003). Hence scientists started to model real-world networks as completely random graphs. The most basic model of network goes back to the probabilistic graph theory models of Paul Erdos and Alfred Renyi (1959). In their seminal paper on random graphs, they assumed that links in a network are randomly distributed between nodes. Mathematically speaking, if there are N nodes which are connected with each other with probability p, the resulting graph will have with approximately $pN(N-1)/2$ edges, distributed randomly. In this model, the average degree of the nodes is $\overline{k} \cong pN$, and the distribution of the nodal degrees follows a Poisson distribution.

However, subsequent research into real world networks gradually revealed the limits of Erdos-Renyi model. It has been observed that a variety of (real) networks exhibit topological properties that do not follow the random networks structure. Significantly, Barabási and Albert (1999) came up with an alternative theory based on real life experiments. According to them, in many real world networks, some nodes have far more links than would be predicted if the number of links per node were randomly distributed. Such highly linked nodes in the network are called '*hubs'*. They are the crucial connectors that hold networks together. Thus, networks seem to display more clustering than what is expected of random networks. Moreover they argued that, far from being random, the distribution of links in many such networks seems to follow a *power law*, which predicts many more extreme cases than a bell shaped distribution does.

In mathematical terms, this would mean that, the probability, $p(k)$, for an actor to be connected with degree k follows a power-law distribution given as:

$$p(k) \sim \Psi k^{-\gamma} \qquad (4)$$

where Ψ and γ are the parameters. The power law distribution means that the frequency distribution of connectivity over the nodes (degrees), when plotted on a double-log scale generates a downward sloping straight line. This kind of network connectivity has been named as "scale-free". The Internet, World Wide Web and many other large-scale networks such as collaboration networks have been shown to exhibit scale-free properties. These kinds of networks show that a very few nodes are connected to other nodes far more than the rest. Power-law distributions of both in-degree and out-degree of a node has also been observed in a variety of networks (Albert and Barabási, 2002; Newman, 2003). The very basis of this type of network is the argument that nodes join *preferentially* to nodes already well connected.

4. Empirical Analysis

4.1. Sources and nature of data

The network database for the study is based on the customer-supplier linkages in the Indian auto component industry. Using secondary source of information, all principal customer links (both original equipment manufacturers and tier-1 firms in the domestic market) as reported by the auto component firms have been used in the construction of the network[8]. The list of firms is taken from the Auto Component Manufacturers Association of India (ACMA). The dataset therefore contains all the auto component firms (called as suppliers) and their customers (buyers).

The information in the network, as defined in Section 3, (i.e., who is connected to whom) is generally represented by a matrix known as the adjacency matrix, in which a given cell x_{ij} contains a value 1 if nodes i and j are connected, and 0 otherwise. In our specific case of automotive network, the nodes 'firms', and 'supplying to a firm' is the link that connects the nodes in this network. Assuming here that through the supply relations the two sets of firms interact with each other, we set up the adjacency matrix (a square matrix) $X_{N \times N}$ (N being the number of firms), where x_{ij} (element of the matrix) represents the existence of a relationship between the i th row and j th column. A matrix value $x_{ij} = 1$ indicates the presence of a link between node i and node j , and $x_{ij} = 0$ indicates otherwise. Thus the rows and columns of the adjacency matrix correspond to the nodes of the graph, and the cells in the matrix correspond to pairs of nodes or dyads. It may be noted here that the relations are not reciprocal (i.e., x_{ij} is not necessarily equal to x_{ji}) as the interactions among firms are clearly (uni-) directional, i.e., one firm supplies to the other, while it is unlikely that the reverse is true.

The data set consists of 618 firms (i.e., $N = 618$). We assume in the analysis that even if two firms are not directly linked they may be linked together through a third firm to which both firms are linked independently. For example, i th and k th firm may not be related, but if both the firms are supplying to firm j, then we assume that i th and k th are also connected. This assumption of indirect connections is central to the social network analysis.

4.2. Characteristic features of the Supplier-Customer network

(a) General features

The network between firms may be examined based on various aspects, such as whether there exists a link between the firms, its strength, or its stability. Directions of links (i.e. outgoing link, incoming link) are also vital as the network under consideration is a directed network. In the network under consideration, in all there are 618 nodes, and 3183 edges in the network. A visual representation of the buyer-supplier network in the automotive industry is provided in Figure 1. Using the toolbox of social network analysis (Netdraw in UCINET 6.2), we use Gower Scaling layout to plot the interactions among various firms[9]. The nodes are coloured on the basis of type of firm i.e., suppliers or customers. Though, the picture is pretty much impressionistic in nature (i.e.,

[8] It may be mentioned here that this list of customers includes only the firms that have been self-reported by the auto component firms as their principal customers. This is compiled by ACMA in their annual publication 'Buyers Guide'. We use the data for the year 2001-2002.

[9] Gower scaling layout plots two nodes close together on the map if they have intense relations either directly or indirectly, through other nodes.

not representing the true distances between nodes), it gives a first-hand impression of the relationship structure.

The general structure of the network can be characterised by some important properties. Table 2 illustrates some of the stylized measures to depict the statistical properties of a network. The first such characteristic is the density of the network. *Network density* refers to “the number of actually-occurring relations or ties as a proportion of the number of theoretically-possible relations or ties” (Garton et al., 1997). We observe that the supplier-buyer network is very sparse ($L/N(N-1) =$ 0.0084*)*: less than 1 percent of all potential links are actually present in the network.

Figure 1: Network of customers-suppliers in Indian auto component industry:

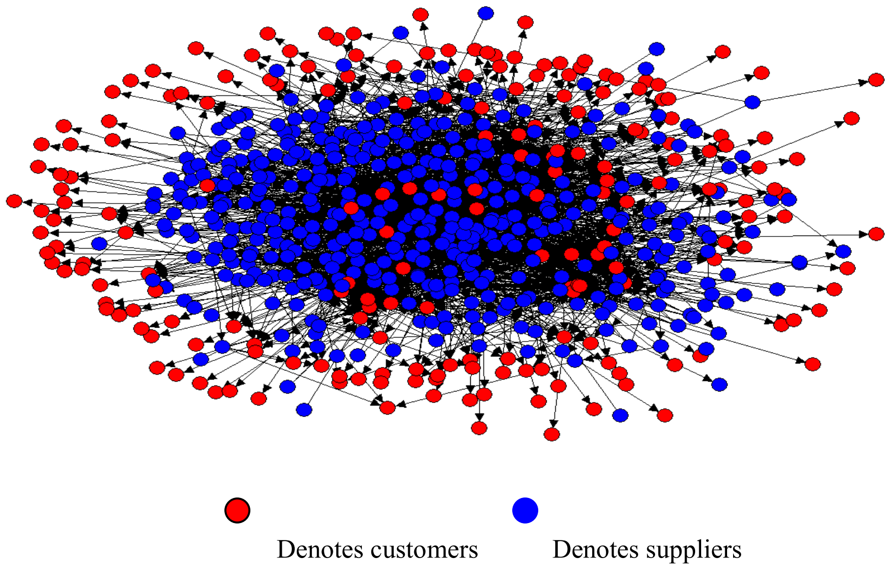


Table 2: Basic Properties of the Network

Characteristics	Complete Network[10]
N	618
L	3183
$Density$	0.008 (0.091)
$\bar{k}_{Own}$	10.301 (18.20)
$\bar{k}_{Random}$	10.233 (3.23)
$\bar{L}$	1.596 (0.683)
$\bar{L}_{Random}$	4.098 (0.956)
$\bar{C}$	0.047 (0.085)
$\bar{C}_{Random}$	0.009 (0.012)

Note: Bracketed values indicate standard deviation

Source: Own calculation

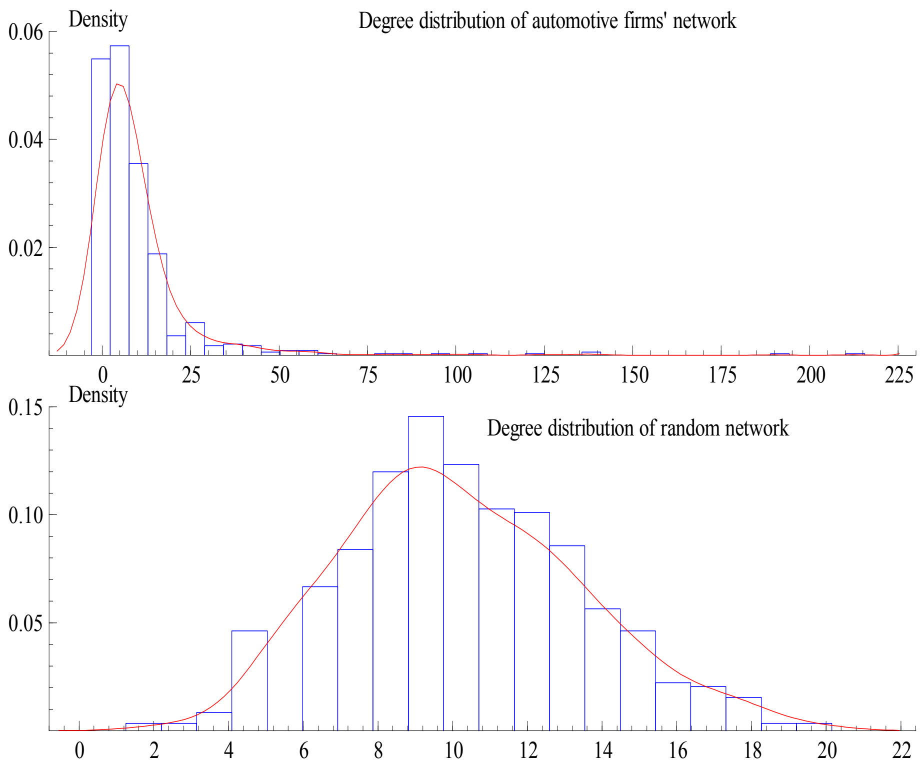
An important feature of the buyer-supplier network can be demonstrated by the way interactions are distributed among firms. In network terminology it is called as the 'distribution of degrees around means' or average degrees. As has been pointed out earlier, real life networks have been found to be rather more uneven than assumed in a Erdos-Renyi type network. Figure 2 presents the plot of densities of degree distribution of our network against a random network, which has been constructed using the same number of nodes (618) and edges (3183) as our network[11]. A clear deviation from a purely random graph is observed in our data. While the distribution of degrees in case of random network is around its mean value, $\bar{k}_{Random}$ = 10.23 with standard deviation, $\sigma_k^{Random} = 3.23$, the buyer-supplier network, depicts a skewed distribution with $\bar{k}_{Own}$ = 10.3, and $\sigma_k^{Own} = 18.2$ (see Table 2). The latter implies that there are few firms in the industry, which have very high connectivity. In other words, as will be clear from the discussion later, there are few buyers who have a big supplier base than the rest. This indeed could well indicate that the buyer firms might have a pronounced position in the industry and a more well-established supplier network that they have developed over time. Thus, in contrast to the homogeneity of nodal degrees, our result conforms to an uneven network giving an indication of a possible scale-free structure.

10 The complete network consisted of 665 nodes from which the largest component (618 nodes) was extracted. All the calculations are based on this component of 618 nodes.

11 This artificial random network is generated in Pajek which is a program under UCINET to analyse and visualize large network datasets.

Figure 2: Distribution of Degrees (Random and Own):

Density Plot (N = 618)



Source: Own construction

(b) Scale-free Nature of Supplier-Customer Network

As shown above, the density of customer-supplier network is very low which means that the average total degree of each node is small compared to the number of possible edges, $N-1=617$. In order to test if the network shows the scale-free property, we analyse the centrality[12] of the network in a greater detail and see if we find evidence to our proposition. As the notion of scale-free network is based on the dynamics of nodal degrees, we focus our analysis on this particular measure.

Freeman (1979) defines degree as the number of ties that a given node possesses. In general, the greater is a firm's degree, the more potential influence it has on the network, and vice-versa. In undirected data, nodes can be distinguished from one another based on how many connections they have. But with directed data, as is the case with our data set, it is important to distinguish between the nature of in-degree and out-degree ties. Actors receiving many ties are often said to be prominent/ or have high prestige in social network terminology. But, actors having high out-degree are those who are able to exchange with many others, making others felt of their power. In

[12] Centrality, also used synonymously with 'prominence' in the social network analysis, refers to the identification of the 'most important' actors in the network. In the SNA literature there are a variety of measures designed to quantify the prominence of individual actors embedded in the network, viz., degree, closeness, betweenness etc., (see Wasserman and Faust, 1994 for definitions of the various measures)

our context, firms having high out-degrees would be the ones who figure as the prominent suppliers to the domestic automotive industry. Indeed it is possible from this measure to find out the prominent auto component firms that play central roles in the industry network.

The out-degrees of the nodes of the network in our case shows (see Table 3) that the network is sparse with relatively high percent of the nodes having out-degrees less than or equal to two. In fact, only a very small proportion of firms supply to more than 20 firms at the same time. Secondly, we can notice that both the out-degree and in-degree show high variation in degrees among various nodes (see Table 4 for the various descriptive statistics for degree centrality). But the range of in-degree is much higher than the same in out-degree, and there is larger variability. From the overall measure, we notice that the power of individual actors varies rather substantially, and this would imply that, overall, positional advantages are *unequally distributed* in this network.

Table 3: Distribution of out-degrees of firms

Degree_range	Frequency	Cum. Freq	% of the total
>=20	13	13	2.103
10-19	112	125	18.123
3-9	219	344	35.437
0-2	274	618	44.336

Source: Own calculation from UCINET 6.2

Table 4: Descriptive Statistics of Degree Centrality

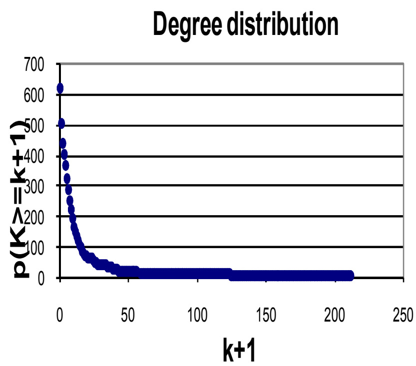
	Degree	**Out-degree**	**In-degree**
Mean	1.670	5.150	5.150
Standard deviation	2.948	5.844	18.295
Minimum	0.162	0.000	0.000
Maximum	34.360	42.000	212.000
Centralisation Index	--	5.982%	33.579%

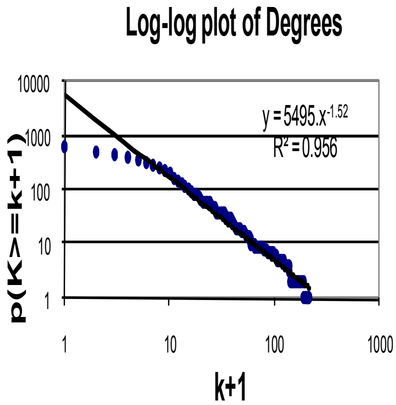
Source: Own calculation from UCINET 6.2

This is very significant as it clearly points to a very highly skewed distribution of interactions in the industry. If we plot the cumulative probability distribution of the degrees on a log-log scale (see Figures 3a through 3c), we find that in all the cases, the degree distributions can be described by power law. The probability distribution of out-degree, for instance, is described by the power law distribution: $p(k_{out}) \sim k_{out}^{-\gamma}$ where, $\gamma = 1.82$ (Figure 3C-Panel B). Similarly we can derive the exponents for the degree and in-degree distributions (Figures 3A and 3B).

Figure 3a: Degree distribution of the customer-supplier network

Panel A: **Panel**

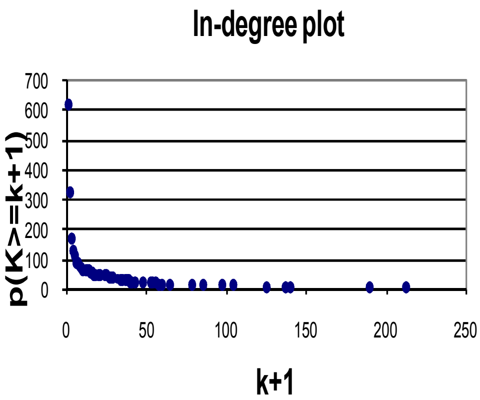




B:

Figure 3b: In-degree distribution of the customer-supplier network

Panel A: **Panel B:**



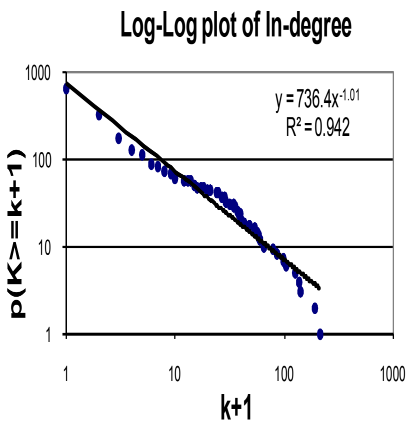
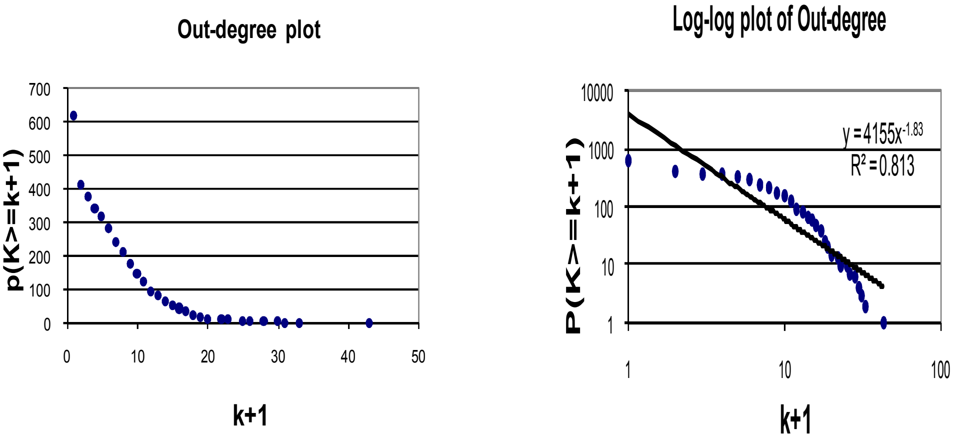


Figure 3c: Out-degree distribution of the customer-supplier network

Panel A: **Panel B:**



Note: Degree distributions (3a: Degree, 3b: In-degree, 3c: Out-degree) for supplier-customer networks –Panel A and B represent the cumulative distribution and their plot on the log-log scale respectively. The straight lines in Panel B in all these figures represent the analytical fits we used. The cumulative distributions show approximate power law regime for each distribution, with the exponents ranging from 1.01 to 1.83.

These facts suggest that power-law describes the supplier-customer network very well. The intuition behind this is that the distribution of degree of nodes is not arbitrary. Rather the lower degrees are more frequent and there are fewer nodes with a higher degree. This result lends support to our hypothesis that the customer-suppler network is scale-free, suggesting that this particular type of network would evolve on the basis of weak or strong ties. This would indicate that the well-connected firms would be strengthening their position in the industry due to their already existing status. In other words, they will attract more customers as the network grows. On the other hand, the relatively sparsely connected nodes will receive less and less attention from customers as the network evolves.

(c) ***Analysis of the Power Concentration***

The scale-free structure of buyer-supplier network points to the existence of certain definite hubs which potentially control and channelize the transactions in the network. This indeed proves the oligopolistic structure of the industry. The industry is predominantly governed by a few big automotive manufacturers. This is also noticed in the structure of the ties among the suppliers and buyers where a few buyers dominate the network. In light of this finding, our hypothesis is that the automotive buyer-supplier networks are core/periphery structures (Borgatti & Everett, 1999) consisting of a central cluster of firms, the core team, forming a network with high density and an external ring around the core which has comparatively low density. In the social network analysis, the core periphery model consists of two classes of nodes, namely a cohesive sub graph, the core in which actors are connected to each other in some maximal sense and a class of actors that are more loosely connected to the cohesive sub graph but lack any maximal cohesion with the core. Identification of core firms in our customer-supplier network might help in assessing the power concentration in the industry. Theoretically, core firms' action and interaction pattern in the network determines the overall pattern of interaction in the network. Due to their strategic position and owning many advantages (like bigger market base, technological advantages, etc.) in comparison to other firms in the industry, the core firms act as leaders and therefore influences the performance and dynamics of the industry. Keeping in mind the useful information core-periphery analysis pertains to revealing the core of the dynamics in the industry in terms of built-in structure and performance, we employ the analysis for Indian automotive industry.

Using the core-periphery routine in UCINET, we first find out the core firms in the Indian automotive industry and short-list the most influential firms in the industry[13]. Though from the knowledge of the industry, we presume that the core firms are mostly automotive manufacturers, the analysis below shows some interesting findings as some component suppliers are also in a strategic position of the network and thereby influencing the nature and intensity of interaction in the network.

In our sample of 618 firms, we find that there are 141 core firms and 477 peripheral firms. Among the core firms, we have presented the top influential firms which consist of 19 automotive and 5 auto component firms (See Table 5). The influential firms are decided on the basis of maximum degrees the firms possess indicating very high connectivity in the network[14]. Given the sophistication in technological base and market domination, while automotive firms are the natural candidates to be recognised and treated as leader firms in the industry, the presence of auto components firms (for example, Motor Industries, Lucas TVS, Fenner India, etc.) in that category is worth noting. In fact, some of these firms are the best performing firms in the industry today and are the crucial players in the industry in India. For example, Motor Industries (known as Motor Industries Company Ltd, MICO and is a subsidiary of Robert Bosch, Germany), has strong presence in the Indian automotive components business with a virtual monopoly in the Diesel Fuel Injection Equipment, Spark Plugs segments and also in the Electric Power Tools segment. Similarly Lucas TVS (a joint venture of Lucas Industries, UK and TVS, India) is one of India's top twenty largest industrial houses with twenty-five manufacturing companies and a turnover in excess of US$ 1.3 billion. The company has a prominent foothold in the design, manufacture and supply of advanced technology systems, products and services to the world's automotive, diesel engine and aerospace industries. The other firm, Fenner India (called as Fenner (India) Limited) is the largest manufacturer and market leader of Industrial and Automotive Oil seals and Power Transmission Accessories in India. Thus the prominence of the firms in the industry seems to be positively linked to their position in the industry network.

Table 5: Automotive Hubs in Indian Industry

Firm Name	Region	Firm type	Degree
TataEngineering (TELCO)	West	Automotive	212
Mahindra&Mahindra	West	Automotive	189
MarutiUdyog (MUL)	North	Automotive	139
AshokLeyland	South	Automotive	136
HindustanMotors	South	Automotive	124
BajajAuto	West	Automotive	104
EicherMotors	North	Automotive	97

13 We have used the discrete version of the core-periphery model (see Borgatti and Everett, 1999 for a discussion of these concepts) using UCINET 6.2. To test the robustness of the solution the algorithm has been run a number of times from different starting configurations. It shows that there is good agreement between these results which ensures our finding that there is a clear split of the data into a core-periphery structure.

14 This is based on a chosen cut-off value of 40 which was considered for our convenience. This was purposefully chosen to see if there are some component firms in the core list of firms in the industry.

BajajTempo	West	Automotive	85
Escorts	North	Automotive	78
HeroHondaMotors	North	Automotive	64
FiatIndia	West	Automotive	59
SwarajMazda	North	Automotive	59
LMLLtd	North	Automotive	57
TVSMotor	South	Automotive	55
TAFELtd	South	Automotive	53
YamahaMotor	North	Automotive	52
HyundaiMotor	South	Automotive	47
MotorsIndustries	South	Autocomp	47
BrakesIndia	South	Autocomp	43
EicherTractors	North	Automotive	42
FennerIndia	South	Autocomp	42
LucasTVS	South	Autocomp	42
KirloskarOilEngine	West	Autocomp	41
GeneralMotors	North	Automotive	40

Note: (a) These are the top players among the Core (141 out of 618) firms.
Source: Own calculation using UCINET 6.2

To provide further insights into the strength of connectivity and closeness of automotive and auto component firms we present in terms of scatter plot (Figure 4) the relation of automotive and auto component firms' connectivity (defined by out-degree) with a closeness metric (defined by the minimum path length). The distance of each of the core (141) firms is calculated from the top 24 leader firms listed in Table 5. The leading idea is to present the vantage or economic value point for each of the 141 firms by defining how far they are from the 24 core firms. Note that the leader firms also comprise in 141 firms, thus the distance between them will be zero. Note that the path length of 1 indicates in our case the direct association of firm *i* with core firm *j*.

The main conjecture is that "*Firms with high connectivity are the ones with minimum path length*", that is the distribution of degrees is positively correlated to minimum path length. This provides evidence of a *small world phenomenon* (Watts and Strogatz, 1998). It is indeed the case if we look at Figure 4 which presents the scatter plot of out degree and minimum path length of 1. The fitted trend shows positive relation with high R^2, implying that the distance provides a significant and robust explanation of strength of connectivity. We found a correlation coefficient of 0.85 between out-degree and minimum path length of 1. Given the power-balance in the automotive supply chain, the leader firms tend to connect among the recognized high-end suppliers (auto component firms) whereas auto component firms continuously try to draw attention to core firms. Auto component firms with high connectivity are thus the most successful firms in the industry (as discussed earlier), the position and development of whom would prove instrumental in defining the dynamics of relation in the automotive industry.

Figure 4: Plot of out-degree and minimum path length of 1

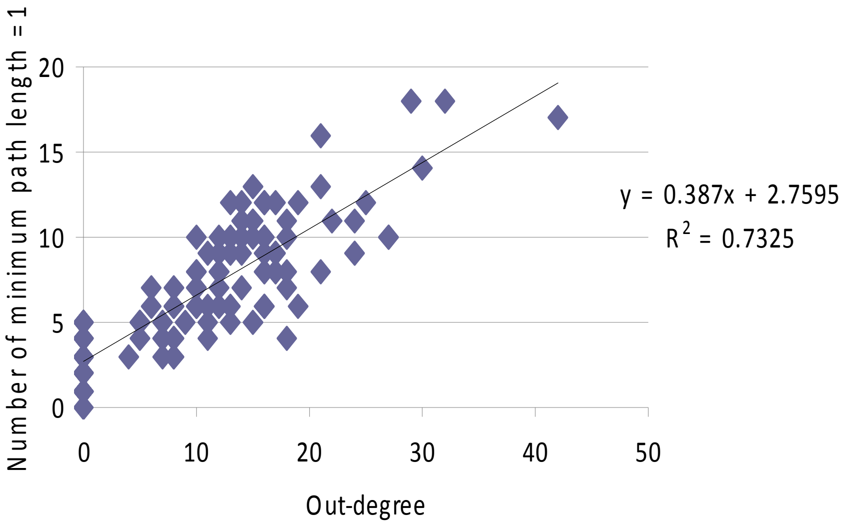
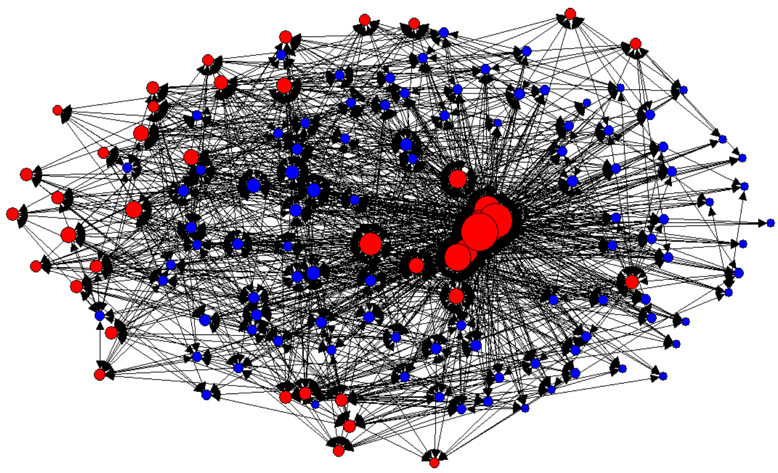


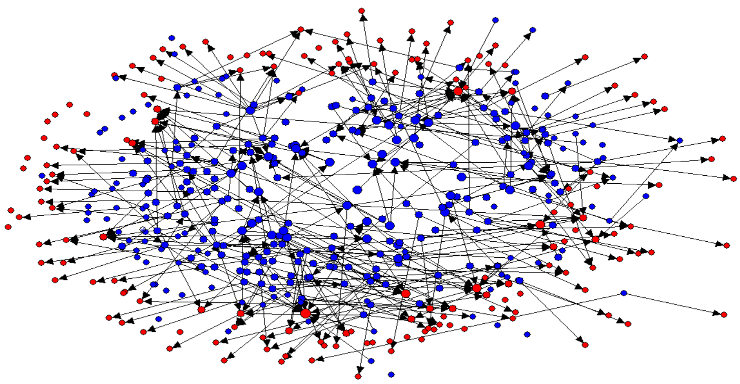
Figure 5: Network of Core-Periphery firms

Panel A: Core firms



Note: This network refers to the connections of 141 core firms. The node sizes are based on nodal degrees. The bigger nodes are the leader firms having high connectivity (see Table 5.4 for the names of the firms).

Panel B: Periphery firms



Note: This network refers to the connections of 477 periphery firms. The node sizes are based on nodal degrees (bigger nodes are the firms having high connectivity).

Denotes customers Denotes suppliers

Figure 5 presents networks among core and peripheral firms in the Indian automotive industry. Panel A of Figure 5 depicts that core firms network have reasonable amount of connectivity and the network therein is dense, while for firms in the periphery depict sparse network with low connectivity (Panel B of Figure 5). Note that bigger nodal size pictorially denote high connectivity (i.e., they have higher degrees). Basically customer firms are the focal point of this network which has very high degree of connectivity to other firms in the industry. Some very important automotive and auto component firms appear in the core firms, though the latter is mostly represented by automotive firms. In the peripheral firms also there are some automotive firms, which are lower- tiered auto component firms. In a way, it is true that leader firms, derived from the customer firms in the automotive industry play decisive role for the evolution of relation and act as guiding force for the entire industry's dynamic behaviour.

5. Conclusion

In this paper we studied the topology of networks in the Indian automotive industry using linkages between the auto component firms and their customers. The topology provided explicit characterization of the automotive firms' interactive structure, their dominance and dependence. The analysis whilst offered direct information about the pattern of interaction of the firms that explains the oligopolistic nature of the industry, also gave indirect clues as to the possible evolution of the industry and its performance. In the literature, analysis of the structure and interaction of firms in the Indian automotive industry so far has been limited to some descriptive measures based on secondary source of information. In this paper, we took the lead to provide insight into the inherent dynamics of the automotive industry by carefully studying the interaction structure of firms in the framework of social network analysis. Many interesting conclusions emerge from our analysis.

First, we found that like many other real world networks studied widely, the automotive industry network also displays a highly heterogeneous architecture by exhibiting scale-free properties. The presence of a handful of leader firms who control most of the resources (in terms of connectivity, in our case) will certainly influence the entry and evolution pattern of the industry over time. Due to the greater market share and greater variety of experience, the leader firms acquire a higher bargaining power and also an automatic tendency to consolidate their prominence in the long run. This can have important implications for the performance and innovation of firms linked to the "visible nodes". As shown in empirical studies (e.g., Parhi, 2006), assured market demand from the already established or leader firms or even assured expertise from the highly efficient firms reduce uncertainty associated with advanced technology adoption for the firms. In other words, close interactive relationships have been associated with a greater technological proximity between the supplier and customer firms. This is not surprising as for any economy, especially in developing countries where firms face an uncertain demand. Therefore, supplier networks with the leader firms in the industry can provide several crucial tangible and intangible ingredients needed for higher productivity and innovation to the auto component firms, the long term success of which are clearly tied to their upstream customers.

Second, we found that there is a core group of firms in the automotive industry around which the peripheral firms build their relation and as a result the relational structure in the industry is highly non-homogeneous in nature. Interestingly, our analysis has also depicted that there are some key auto component firms in the influential category which potentially lie between the resourceful core firms and peripheral firms and hence could pose to be a possible broker between the two extremities. In the context of diffusion of new technologies or innovative performance of firms, our analysis provides useful insights. For instance, small firms heavily look upon the know-how and resources of large buyer firms, and strong networks/ interactions with the latter can prove immensely valuable to these firms in order to improve their technological capability. If peripheral firms have assured market demand and have strong ties with the core automotive firms (customers), then adoption could become easier and faster.

Third, the scale-free feature in the industry network has considerable policy implications. From a policy perspective, it will be imperative to monitor the growth and behaviour of these leader firms in the industry. Given the current performance of the automotive industry, appropriate measures can be initiated to improve the performance of the industry by selective policies aimed at the 'high-connective' nodes, or leaders. We found that the automotive industry's dynamics is mostly led by the presence of some leader firms (both automotive and auto components).Given the huge heterogeneity of the automotive industry, identifying the right leaders is important from a policy view point so that successful firms can provide a "light-house effect" in the industry. This feature of scale-freeness can also have interesting implications for movement and impact of 'productivity or technological' shocks and consequently the quicker way to control the spread of the shocks in the entire industry.

Our results also point to the joint dynamics of performance and network. The study demonstrates that the industry seems to follow the *fitter*-get-richer model of network growth, with preferential attachment to firms holding key positions. This paper highlights the strategic importance of understanding the growth dynamics of the industry in terms of the structure of networks. A further analysis of the network data in terms of categories of nodes (control and decision based) might prove valuable in understanding the effect of network structure on the industry dynamics. As a future step, it is intended to incorporate the economic indicators/ background of the firms into the network structure to understand the underlying dynamical mechanism in the network model.

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