**Does Supply Chain Network Affect Firms Performance?**

*‘for consideration for JPSM learning from the pandemic special issue’*

**Abstract**:

The COVID-19 pandemic highlighted the fragility of the modern efficient and optimized intertwined network of the global supply chain. This pandemic was the black swan that professionals in the medical supply chain field had noted its threat in recent years. Considering the short-term and long-term effects of changes in the global supply chain this research explores how the location characteristics of the firms across the supply chain affect their performance. Using the mined data from five tiers of the backward supply chain of medical equipment we constructed a large supply chain network consisting of close to 160,000 dyadic connections. Furthermore, we ran a scenario to simulate the elimination of Chinese firms from the global supply chain to study the effect of such a change on firms’ performance. The result of this study provides notable insight into how various measures of network centrality affect firms’ performance.

**Keywords**: Medical Equipment, Supply Chain, COVID-19, China, Network Centrality, Network Analysis, Financial Performance

**1. Introduction**

Does supply chain management matter? The very real impact of COVID-19 on firm performance has put the cost and reliability of the supply chain in the crosshairs of U.S. government policy. On the one hand, there are practical reasons why a firm chooses to have fewer, reliable, suppliers to reduce inventory costs and maximize shareholder profits. On the other, the very same reasons a firm chooses to have a lean supply chain can result in over-dependence on a handful of foreign suppliers who may be beholden to none other than their own foreign governments. The latter can seriously jeopardize the timely, cost-effective, delivery of critical products. The problems are magnified for the customer firm which uses the Just in Time (JIT) and Zero Inventory Production Systems (ZIPS) manufacturing philosophies. In this pandemic era, the issue of foreign suppliers has not gone unnoticed by U.S. firms and the U.S. Government. This is especially true for the supply chain of emergency medical supplies and equipment. When pandemic strikes all countries simultaneously nationalistic fervor takes precedence over rational decision making. Sovereign countries start protecting the supplies originating within their borders. Any external shock to supplies has a domino effect throughout the supply chain. These reverberating effects impact operating costs that may have a far-reaching effect on a firms’ performance beyond the proverbial annual financial statement. The primary focus of this study is to investigate what impact, if any, does the supply chain network has on a firm’s performance.

The importance of the supply chain network for the success of the firm has been addressed by many academicians (c.f. Chen and Chiang, 2011; Todo, Matous, and Inoue, 2016; Carnovale, Rogers and Yeniyurt, 2019; Wang and Hu, 2020). Willis (2006) contends that logistic issues, in normal times, of low-tech equipment such as Protective personal equipment (PPP), can be handled through inexpensive purchasing. During abnormal times, plans need to be in place to deal with geographically expansive supply chain disruptions (Syahrir, Suparno, and Vananyl, 2015). According to Syahrir et. al (2015) and Ivanov (2020), these special or extraordinary situations may further cause disruptions in manufacturing. A system with an overreliance on JIT, ZIPS, and, other lean delivery systems and efficiency practices using “complex value chains and the international shipment of billions of components” is simply incapable of managing operations under abnormal conditions (Sarkis, Cohen, Dewick and Schrodel, 2020). The complex multi-tier global supply chain of medical equipment and in particular the “impact of epidemic outbreaks on the commercial” supply chains has been somewhat overlooked by researchers (Ivanov, 2020). The advanced and celebrated, efficiencies, and optimizations practices became the Achilles heel of global trade and operations during the COVID-19 pandemic.

In a much-celebrated article in Harvard Business Review, Lyall, Mercier, and Gstettner (2018) predict that the supply chain function may become obsolete and be replaced by a smooth, “self-regulating utility” with little human interference. Others (c.f. Ambulkar, S., Blackhurst, J. and Grawe, 2015; Schniederjans, Curado, and Khalajhedayati, 2020) casts doubt on this point of view. Our study on a relatively exclusive industry (medical equipment) revealed that the 5-tiers backward supply chain in this industry includes close to 160,000 dyadic connections spreading around the world; Such structure is ripe for various interruptions and black-swan events (Taleb, 2007) caused by “destabilizing factors” such as “powerful weather, pandemic, port closures, and political instability” (NASEM, 2018, p. 10). Considering the current state of the global supply chain, the claim of “the death of supply chain management” (Lyall et al. 2018) may be considered only as a “provocatively titled” work (Sank, Esper, Goldsby, Zinn, and Autry, 2019).

Post-COVID-19, there seems to be a consensus in the literature that commercial supply chains, particularly those related to pharma, medical supply (Stellinger, Berglund, and Isakson, 2020) and medical consumables, medical equipment, and medicines (Evenett, 2020) should prepare for potential implementation of protectionism by nations around the world. The protectionist policies may not necessarily “address the root causes of the challenge” (Evenett, 2020) however such policies seems to be inevitable even though they may be “costly for the world economy” (Furceri, Hannan, Ostry and Roe, 2020). The World Trade Organization (2020) expects a short-term 13% to 32% decrease in the global trade in 2020. Businesses and policymakers could face with long-term changes stemming from “trade discriminations”, “dismantling the international supply chains [and] reliance on domestic production” (Yacoub, and El-Zomor, 2020, pp:11). It is expected that the tariffs and protectionist policies will affect the “location decision” of firms which in turn will result in changes to the structure of global supply chains (Culot, Orzes, Sartor, and Nassimbeni, 2020).

The management of global supply chain of medical equipment can be studied from different perspectives such as pricing (Ma, Gong, Jin, 2019), surplus management (Atasu, Toktay, Yeo and Zhang, 2017), quality assessment (Kong, Xu, Yang and Ma, 2015), medical waste supply chain management (Alizadeh, Makui and Paydar, 2020) and corporate social responsibility (2018) to name a few. Some of the previous studies have explored healthcare in the context of disasters. The focus of this study is on the global aspect of the supply chain and how a rupture in the supply chain can affect the performance expectations of the firms. In the present study, we also explore how the elimination of a notable country from the global supply chain affects the centrality of the remaining actors in the global supply chain. In the simulation, we remove all firms headquartered in China (including Taiwan, Macao, and Hong Kong) and rebuild the global supply chain network to assess how the relationship between firms’ position in the network and firms’ performance changes. The COVID19 global pandemic experience highlighted the difference between a local or limited interruption and a global rupture in the supply chain. In this section regression analyses of the models including and excluding China are presented.

This paper is motivated by a serious deficiency in analyzing the financial consequences of the change in the structure of the global supply chain network of medical equipment where a cluster of firms get eliminated as a result of the nationalistic policies of protectionism and tariff barriers. In this paper, we estimate a model of firm performance, measured by both accounting and market performance, using data form 3,739 firms, across industries, for 2019. When China is included in the supply chain network, our results provide convincing evidence of a highly statistically significant positive relationship between firm performance and centrality measures, a finding that remains robust across a number of different model specifications. However, when we exclude China some of the centrality measures are no longer significant while others exhibit a negative effect on firm performance.

The remainder of the paper is organized as follows. In section 2, we provide the theoretical background, examine extant literature, and discuss network centrality measures. In Section 3 we develop the general hypothesis. Section 4 discusses the research design, including sample selection, and descriptive statistics. In section 6 we report the empirical results. Results from a number of robustness tests are also discussed. Sections 7 and 8 deal with conclusions and limitations.

**2. Literature Review:**

**2.1 State of Global Supply Chain in the Medical Equipment Industry**

The medical equipment supply chain has been studied over the past several decades from various perspectives. Few researchers have explored this domain from a network perspective. These studies range from the analysis of the supply chain at the firm level and industry level, to the regional and global level. One example is the work of Nagurney and Nagurney (2012) molybdenum supply chain network which has applications in medical equipment. Nagurney and Nagurney (2012) further emphasized the importance of transportation and disposal of the hazardous waste which is not the subject of this study as we are primarily focused on manufacturing and production network of the medical equipment. Medical equipment along with drugs is a “key input in the healthcare sector” with expected $119.98 billion growth during 2018-2022 (Jha, 2019). The global supply chain and production of medical equipment has experienced significant transformations over the past few decades (Jha, 2019). In one of the early studies on the cross-industry supply chain of medical equipment (Standard Industry Code 5047) Maltz and Maltz (1998) explore the similarities and differences of medical equipment supply chain versus industrial equipment supply chains. They argue that the availability and on-time delivery of medical equipment have been better than that of industrial equipment and supplies. However, Maltz and Maltz (1998) find it “surprising” that “mean order cycle time is longer for medical products distributors versus industrial supply distributors”. They also provide evidence that supply chain channels of medical equipment require a higher level of service. However, over the past few decades supply chain of medicine and medical equipment has become more efficient and lean compared to other industries (NASEM, 2018). Four distinct trends affected the global supply chain of medical equipment (Jha, 2019). The first trend is the separation of original equipment manufacturers (OEM) from other support activities including distribution and inventory management. In such an environment the purchasers have greater control over the distribution channels and could be more favorable in using channels that can maximize their margins. The second trend is the role of governments in mandating product specifications and pricing, which varies from one country to another. The third trend is diminishing product differentiation through brands. For example, medical equipment manufactured in India using less complex production processes can have comparable quality and performance to a piece of medical equipment manufactured in high-cost countries in more technologically advanced firms. The fourth trend is the consolidation of firms and industries on a global scale. These same trends which were celebrated up until 2019 (c.f. Jha, 2019), have now become points of concern for individuals, firms, and governments around the world. A recent survey from National Association of Manufacturers (NAM) conducted in early 2020 (NAM report, 2020) from US manufacturers revealed 35% of respondents reported facing supply chain disruptions as early as February/March of 2020, while 53% reported that they expected changes in their operations as a result of COVID19. An overwhelming proportion of respondents (78%) reported uncertainty about the financial impact of supply chain disruption on their business; this latter information highlights the magnitude of interruptions on the business environment. While this research is being conducted in the early months of this pandemic, future research can provide a more comprehensive assessment of the scope and magnetite of the supply chain disruption at the national and global scale.

**2.2 COVID-19 and the Global Supply Chain of Medical Equipment:**

Ivenov (2020) describes three reasons as to why epidemic outbreaks are special cases of supply chain risk. These reasons include uncertainty about scale and duration of the disruption, ripple effects of disruption among people and supply chain actors, and disruption in operational infrastructure (Ivenov, 2020). Unlike the other pandemics of the past including Ebola, MERS, and SARS, the COVID-19 has already imposed long-term changes to global supply chains as a result of “rising protectionism” and the “global financial crisis” (Salvatore, 2020). Javaid et al. (2020) in their study on the fourth industrial revolution (Industry 4.0) and medical equipment manufacturing, provided evidence that even before the recent pandemic there had been explicit interests and actions toward reshoring manufacturing. The advancements in redistributed manufacturing (Hannibal and Knight, 2018) can further facilitate the localization of manufacturing in a post-COVID19 political and business environment. In this study, our focus is on investigating the long-term financial consequences of rupture in the medical equipment supply chain. This study considered the possibility that as a result of COVID19 experience, many countries may consider realigning their global supply chain of medical equipment. As a result of such changes in the global supply chains, policymakers and businesses could experience changes in their supply chain strategy. This study specifically explores the effect of firms’ supply chain network influence with and without China on the firms’ performance.

The root of vulnerability in the medical equipment supply chain manifested well before the 2019 epidemic. In addition to the global nature of supply chains (Ivenov, 2020), Shokrani, Loukaides, Elias, and Lunt (2020) argue that two other factors have contributed to the vulnerability of the global supply chain of medical equipment “due to the global coronavirus (COVID) pandemics”. The first factor is that the manufacturing of medical equipment in advanced economies have become more “focused on manufacturing low-volume, high-value, [and] high-margin products” over the past few decades. The second factor contributing to the increased supply chain vulnerability to such interruptions is the dominant supply chain management practices promoting leanness and efficiency across the global supply chains.

Denton and Jaska (2014) in their study on supply chain management of medical devices described how the industry was “forced” to increase operational efficiencies through efficiency practices such as “pull”, “push”, “just-in-time (JIT)”, as well as reducing inefficiencies across processes and production cycles. Denton and Jaska (2014) further describe how companies associated with medical devices gained “economies of scale through off-shoring production to improve transportation costs in global markets.” Such globalization was forced upon the industry with the promises of “improved quality of care, lower healthcare costs, and sustainable competitive advantage for the suppliers willing to invest in efficient inventory management controls.”

As the globalization of manufacturing medical equipment along with offshore sourcing of OEMs were promoted over the past few decades, the literature has also recognized the increase in challenges and vulnerability risks associated with such practices (c.f. Goh, Lim, and Meng, 2017 and Hasani, Zegordi and Nikhbakhsh, 2015). It is important to note that such studies try to develop mathematical optimization models that can address limited, local, and short-term disruptions to the supply chain. In the post-COVID-19 business environment, companies may face the elimination of several countries from the global supply chain due to long-term national security concerns. Such optimization models may not provide helpful tools in such a business environment. In this study, we explore how the relationship between supply chain network characteristics of firms and their financial performance changes in case of such long-term changes by simulating the change in the global supply chain network.

**2.3 Supply Chain Network and Firms’ Performance**

Ivanov and Dolgui (2020) in their position paper on supply chain and COVID-19, highlighted the importance of modeling supply chains through biological systems. The roots of studying complex systems using ecological models can be traced back to the work of Ludwig von Bertalanffy during the 1950s on General System Theory (GST). Ludwig von Bertalanffy (1968) has a holistic view of the systems where interconnected sub-systems shape the system. Von Bertalanffy’s view which is based on “systematic interactions of the parts as a whole,” is defined as opposed to the reductionism view (Thacker, 2004). Thacker (2004), in his work on molecular biology and computer science, describes Bertalanffy’s holistic view of the organisms as “systematic interactions of the parts as a whole,” which is defined “in opposition to reductionism." More recently this Bertalanffy’s holistic view of the supply chain has been explored in the context of the supply chain (c.f. Wang, Muddada, Wang, Ding, Lin, Liu, and Zhang, 2014; Wang, Dou, Muddada, and Zhang, 2018). Wang et al. (2018) further discuss the relationship between supply chain networks and the global financial crisis of 2008. Wang et al. (2018) also argue that firms’ positions with respect to upstream and downstream contribute to the firms’ performance. In the present study, we hypothesize that firms’ position in the supply chain structure will affect their financial performance. This study focuses on the upstream tiers of the supply chain in medical equipment manufacturing. Specifically, we explore the five tiers of the backward supply chain. More information about our data structure is presented in the data collection and data preparation section.

The factors affecting the firms’ differential performance have been a subject of interest in several fields particularly among scholars in the field of strategic management (Rumelt, Schendel and Teece, 1991, as cited in Dyer and Singh, 1998). One of the questions facing scholars has been the unit of analysis in studying the factors affecting firms’ performance. Michael Porter’s (1980) industry structure view “suggests that supernormal returns are primarily a function of a firm’s membership in an industry with favorable structural characteristics [such as] bargaining power, barriers of entry, and so on.” (Dyer and Singh, 1998). This suggests the unit of analysis should be at the industry level and researchers should consider industry-related factors. Contrary to the industry structure view, the resource-based view suggests the unit of analysis should be the firms since it is the accumulation of rare intra-organizational “resources and capabilities” that enable firms to achieve higher levels of performance (Dyer and Singh, 1998).

Based on a discussion of some of the shortcomings of the industry structure and resource-based views, Dyer and Singh (1998) suggest that firms should look at sources of firms’ competitive advantage beyond their boundaries as well. “The network of relationships in which the firm is embedded" creates “relational rents” that enhance a firm’s competitive advantage across the network (Dyer and Singh, 1998). Furthermore, Carnovale, Rogers, and Yeniyurt (2019) highlight the role of resource dependency theory in explaining the relationship between firms’ advantages through its network and the firms’ performance. Following the relational view of competitive advantage, in this study, we consider centrality measures as indicators of a firm’s relationship with its supply chain network.

Other concepts that can support the network view and relational view of the firms in the area of supply chain management include knowledge-based view and network perspective (Lavassani, Movahedi, Kumar, 2008). Thanks to advancements in telecommunication and computing technology the knowledge can transfer across supply chains and supply chain networks can be viewed as platforms “where knowledge can be viewed as a quasi-public good to be shared across the member firms” (Samuel, Goury, Gunasekaran and Spalanzani, 2011).

Network perspective (also discussed as network theory; c.f. McNicholas and Brennan, 2006; Mander, Caniëls and Ghijsen, 2016; Bombelli, Santos and Tavasszy, 2020) describes that firms seek competitive advantage based on the structure and content of inter-organizational relations that they have among the group of other firms (Moller and Wilson, 1995). While resource-based view and relational view focus on the dyadic relationships in the network, whereas the network perspective focuses on multi-party inter-organizational relationships (Reekers and Smithon, 1996; McNicholas and Brennan, 2006). Hence we believe network perspective adds a notable dimension to the analysis of global supply chain networks.

In recent years increasing attention has been paid to explore the effect of firms’ position in the supply chain network on the firms’ financial performance. While most of the studies in this area are conceptual, notable few have conducted important case studies and single-tier empirical works. For instance, Li, Zobel, Seref, and Chaffield (2020) made contributions in this area using a case study of an auto supply network in Japan and Apple Inc. Li el a. (2020) highlight the limitation of their network analysis and call for further research using a larger scale studies beyond their sample. In another study, Carnovale, Rogers, and Yeniyurt (2019) conducted a single-tier study on 1985–2003 joint ventures to explore this domain. Carnovale et al. (2019) described that they used the joint venture network as a proxy to study the supply chain network. They explored the role of *eigenvector centrality* and *ego network density*, on firms’ performance. The findings indicated that in the network of joint ventures, higher eigenvector centrality contributed to the firms’ financial performance. Carnovale et al. (2019) called for using more updated data, along with studying other centrality measures beyond eigenvector centrality. Our work will address some of these limitations by directly honing on the most recent supply chain network (instead of studying a proxy network) using several centrality measures. Another notable contribution of our study is the use of multiple tiers of the supply chain on a vast scale.

**2.4 Firms’ Performance and Network Centrality**

As discussed previously relational and network views of firms provide important new insight about the firms' inter-organizational relationships and performance. In the current literature, the application of network in the study of the organizational supply chain is either focused on *optimizing* networks, or it is focused on utilizing the *network science* approach (Li, Zobel, Seref, and Chatfield, 2020). We utilized two primary tools from a network science view namely centrality to the measurement of firms’ importance and influence, and clustering to assess the membership of firms to a group of closely related firms. In this study, we used nine measures of centrality, namely: indegree, outdegree, eccentricity, closeness, eigenvector, authority, page-rank, cluster size, and clustering coefficient. The networks can be either directed or undirected. Some networks are undirected, such as the network of strategic alliances of the firms, or network of friendships. However, in the case of the supply chain, the network is inherently a directed network. The type of network edge (to be directed or undirected) affects the calculation of most of the network centrality measures we used in this work. In the following, we discuss the measures that we used along with their implications in firms’ performance.

The degree of the firm in one of the measures that indicate the level of emergence of the firm in the supply chain. The in-degree and out-degree can illustrate the level of interdependencies of the firm. In general firms with a higher number of suppliers and customers will be able to better protect themselves against opportunistic behaviors of few actors, due to the availability of alternative suppliers and customers. These firms may have less exposure to risks and interruptions, which can lead to higher financial performance. Firms with a higher number of suppliers (higher in-degree) can substitute specific-purpose assets with general-purpose assets; this can lead to higher financial performance (Dyer and Singh, 1998). Firms with a higher number of customers (higher out-degree) may have less specialized products which in turn may lead to the expectation of lower profit margin while firms with a higher number of suppliers may be producing more complex products with a higher profit margin. Also, firms with higher dependencies in the supply chain may be more influenced as a result of interruptions in the global supply chain. Our simulation of disruption as a result of the elimination of country from the supply chain would provide an important contribution to our understanding of firms’ performance and asset management as a result of similar large scale interruptions. In the following section, the measures of centrality and their interpretations of the study of organizational supply chains are discussed.

**Degree (In-degree & Out-degree):** One of the common measures of influence in supply chain networks is the degree, which is defined as the number of connections a firm has with other firms. The supply chain network developed in this study is a directed network. Consequently, we can have distinguished measures of degree, which are in-degree and out-degree. In-degree measures the number of notable suppliers that the firm has, while the out-degree measures the number of notable customers that a firm has.

In general, as we move across firms from the industry-specific product manufacturer to firms in higher tiers backward supply chain we expect to see a lower degree. The reason is that higher-level tiers are generally manufacturing relatively more standardized, simple products that go into the more technologically complex product in lower tiers. This means a higher tier supplier (e.g. the supplier of a plastic tube) will have lower in-degree and out-degree in comparison to a lower-tier firm (e.g. the manufacturer of the ventilator) which assembles several parts into one product. Our data also supports this view. It is important to note that many firms contribute multiple times to the global supply chain at different tiers; therefore we calculated a measure of weighted-tier for each firm to represent its role across different tiers of the supply chain network.

**[Insert Table 1 here]**

Extant literature has examined the role of the number of suppliers and customers in firms’ performance. For example, Nuss, Graedel, Alonso, and Carroll (2016) argue that in-degree is a measure of the complexity of the product while out-degree is a measure of product diversity. It is important to note that while the quantity of connections is important so is its quality. Generally higher in-degree (suppliers) and out-degree (customers) provide the firms with less dependency and provides higher bargaining power for the firm. A firm with high in-degree may have higher bargaining power and more efficient as a result of having less specialized assets (Dyer and Singh, 1998). On the other hand, a firm with high out-degree may have more limited product variety and tooling to manufacture a limited number of products at high volume with a lower profit margin which is more of commodity-type products. Chen and Paulraj (2004) posit that while a higher number of suppliers provide a competitive advantage for the firms, the firms can still gain a competitive advantage with lower in-degree should they be able to build quality strategic relationships. In our data, while all suppliers and customers are notable partners our data does not include the level of strategic partnership. Future research is required to conduct a multi-layer network of supply chain analysis along with strategic alliance networks.

**Eccentricity**: The eccentricity of each firm is the maximum distance (shortest path distance) of the firm and all other firms. The eccentricity of a firm in the supply chain network is another measure of a firm’s influence on the supply chain. Firms with higher eccentricity are involved in the production of products that require higher “transformation steps” (Nuss, Graedel, Alonso, Carroll, 2016). We argue that firms with higher eccentricity are mor entrenched across the industry as a whole. Eccentricity is distinguished from other centrality measures used in this work as it is the only measure that we utilize in this work which is a representative of distance in network science.

**Closeness:** Closeness centrality measures the “average supply-chain length”; It “measures the length of the average shortest path between the” firm and all other firms in the supply chain network (Nuss, Graedel, Alonso and Carroll, 2016). Firms with lower closeness “are connected to shorter supply chains”, are “less likely to encounter distortion”, “their supply chains are at lower risk” (Nuss et al., 2016) and have higher “distance [from] all other” firms (Li, Zobel, Seref and Chatfield, 2020). Li et al. (2020) describe that increased closeness can be a sign of a disruption taking place across the supply chain.

**Eigenvector:** Eigenvector centrality isone of the most commonly used global measures of the importance of a node in the network(Li et al. 2020). “Global” measure here is defined as opposed to a “local” measure. A global measure takes into account the whole connected network to measure the importance of a node (Besri and Boulmakoul, 2017). For example, in the case of eigenvector centrality, all the nodes in the network are given a score and the importance of each node is measured based on the importance of its forward and backward connections. However, in-degree and out-degree are considered local measures since the importance of each node is based in immediate backward and forward connections.

We hypothesis that firms with higher eigenvector are expected to be able to capture more value and could have better financial performance in comparison to their industry competitors.

**Authority**: According to Kleinberg (1999) ‘Authority’ refers to the “most often” or “most prominent” node in the network. As authority uses direct network and hubs to identify the utilization of a node in a network. “Hubs are nodes which point to many nodes of the type considered important [and] authorities are these important nodes” (Benzi, Estrada and Klymko, 2013). Firms with higher authority measures “more diverse are its relationships due to flows of different product-types within the network” (Seiler, Papanagnou and Scarf, 2020). These firms have higher negotiation power, their products are more complex, and their profit margins are expected to be higher.

**Page rank:** Page rank identifies the firms where most of the supply of the network end-up. Firms with higher page-rank receive inputs from a larger number of firms. This measure is similar to in-degree. However, while in-degree is a local measure, page-rank is a global measure, and takes into account the entire network. It is not surprising to see a 0.76 correlation between in-degree and page-rank (Table 1). Firms with higher page-rank have operations similar to an OEM that produce a final product or close to the final products. Such firms are producing more complex products and we expect such firms to have higher financial performance. However, since these firms may be more specialized in their field they could be more affected by disruptions in market demand as they may not be able to re-tool their facility easily to enter other markets.

**Clustering coefficient**: The clustering coefficient measures the likelihood of a firm being part of a highly connected group of firms. A firm with a higher clustering coefficient is more embedded with its customers and suppliers. These firms are expected to operate closely with firms in a similar industry. A high degree of product, information, and technology sharing is expected from firms with higher degrees of clustering coefficient. A firm with a higher clustering coefficient (unless it is the cluster leader as identified by other centrality measures such as page-rank or eigenvector) is expected to have moderate financial performance. The firms which have a high(low) clustering coefficient and at the same time are high(low) centrality are expected to be best (worst) performers. **Cluster size:** Cluster size is a simple measure that we developed to measure the size of the cluster that firms are a member of it. Firms that are in smaller clusters are expected to lack a significant cluster leader, are exposed to supply chain volatility, and report lower financial performance.

**3. Hypotheses**

There is a paucity of empirical literature examining the relationship between a firm’s location in the supply chain network and the firms’ performance. One of the few studies in the area was recently published by Seiler, Papanagnou, and Scarf (2020) using a small sample of firms (15 focal firms). Another study in this area is conducted by Su, Kao, and Linderman (2020) where the authors argue that firms’ position in the supply chain network affects the firms’ competitiveness. They provided evidence that firms that are more central in the supply chain benefit more from process management programs. Su et al.’s (2020) work was conducted using a sample of firms from 1998-2005 and it is not clear if the network is focused only on a particular type of supplier/customers or it includes all types of relationships (e.g. supplier of parts/service to the firm vs. landlord, banks, license providers, etc.). Also, it seems the data is collected from a single tier of the supply chain across different industries and no systematic effort is made to track the supply chain tier by tier. As a result, their results cannot directly be generalized.

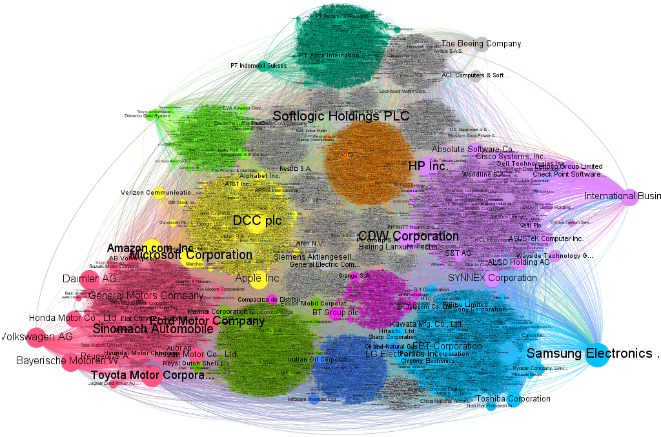
Our work is the first comprehensive large scale study that systematically investigates the supply chain of one focal industry (medical equipment) across five backward tiers of supply chain expanding throughout the globe. Based on the review of the literature discussed in this paper, we hypothesize that firms' degree of centrality in the global supply chain network will affect the firms’ financial performance. Based on the discussions presented in the previous section on the relationship of centrality measures and firms’ performance we propose four hypotheses that suggest firms’ position on the supply chain tier and measures of centrality influence two measures of firms’ accounting and market performance. Particularly we hypothesize that various measures of the centrality discussed in section 2 will impact firms’ financial performance as measured by return on assets (ROA) (H1), and Tobin’s-q (Q-Ratio)(H2). We also hypothesize that firms’ locations across the five tiers of the backward supply chain will impact their ROA (H3), and Q ratio (H4).

**4. Research Design**

*4.1 Sample*

The data was mined and compiled from the financial records through several rounds of data collection and data preparation for each supply chain tier. The starting point for data collection was the professional and commercial medical equipment and supplies classified under standard industry code (SIC) 5047. SIC 5047 is described as medical, dental, and hospital equipment and supplies. After identifying 324 firms in SIC5047 we extracted data about their backward supply chain connections over five tiers. We identified 1175, 4464, 21775, 32243, and 157438 backward dyadic connections across tiers one to five in order. The backward connections include numerous stakeholders such as creditors, landlords, lessors, licensors, suppliers, transfer agents, and vendors. To ensure that our data is focused on the medical equipment supply chain, we progressively eliminated the firms which were not directly involved in supply chain activities at each tier. As a result, the original network of 266,093 edges was reduced to 88,397 edges. The 5-tiers of the backward supply chain include 21,716 unique firms. The availability of financial information is mostly limited to public firms and only available for 3,826 firms. To conduct the comparative analysis 637 Chinese (headquartered in China, Hong Kong, Macao, and Taiwan) firms were removed from the sample. The network centrality measures were calculated using the whole network to provide the most accurate measure of the global network characteristics of the firms. Figure 1 displays the 5-tiers visualization of the supply chain network.

Figure 1: Visualization of the 5-tiers Supply Chain of Medical Equipment



In the visualization presented in Figure 1, node and text sizes represent the firms’ eigenvector centrality. The colors distinguish the clustering using the Blondel, Guillaume, Lambiotte, and Lefebvre (2008) community identification clustering algorithm. At the 5-tiers supply chain network, 93 clusters were identified. The distribution of the size of communities is presented in Appendix 1. These firms represent 844 industries defined within SIC and 138 countries. The top six industries[[1]](#footnote-1) (measured by the number of firms from those industries) contributing to the global medication equipment are 1. Computer programming, data processing, and other computer-related services (10,559 edges), 2. Motor vehicles and car bodies (9,225 edges), 3. Semiconductors and related devices (8,740 edges), 4. Prepackaged software (8,246 edges), 5. Motor vehicle parts and accessories (6,363 edges) and 6. Pharmaceutical preparations (5,513 edges). The top six countries where the firms in this supply chain are headquartered are 1. United States (52,108 edges), 2. China (22,752 edges; 11,707 edges in mainland China, 9,696 edges in Taiwan, and 1,349 edges in Hong Kong), 3. Japan (19,709 edges), 4. India (10,844 edges), 5. South Korea (8,112 edges), and 6. Germany (6,992 edges) (see Appendix 2).

*4.2 Descriptive Statistics*

Table 2, presents the distribution of our sample by industry and median values of the study’s main variables. We use the widely used Fama & French 12-industry classification.[[2]](#footnote-2) The industry distribution of our sample is similar to prior studies using comparable data, e.g., Frankel, *et al.* (2002) and Whisenant, *et al.* (2003). Table 2 also reports the median of the ten centrality measures for all firms by industry. The data indicate that companies in the utilities, chemicals, and non-durables industries, on average, have the largest median accounting returns (all in excess of 10% *ROE*) In terms of centrality measures, on average, utilities have the highest tier (4.92) and as expected the lowest outside degree (2.29). Conversely, the health industry which has the lowest tier (3.74) also enjoys the highest in-degree measure (9.2). On average, companies in the business equipment industry have the largest eigenvalue while firms in the utilities industry report the highest eccentricity.

Other descriptive statistics are also interesting. For example, companies in the durable industry had the highest cluster size and out-degree centrality. It is also worth noting that, firms in the utilities industry, on average, had the highest eccentricity (14.33) with the highest median accounting return (ROE of 11.39%), while firms in the energy industry had the highest cluster (CLT of 1758 and highest IDG of 7.77) but reported the lowest median accounting returns (ROE of 6.83%).

**[Insert Table 2 here]**

Table 2A reports the overall descriptive statistics for all the firms. Table 2B also presents the Pearson correlation coefficients for the main variables of the model. Inspection indicates that though a number of the correlations are statistically significant, their magnitudes do not raise collinearity concerns. Additionally, variance inflation factors (VIF) tests found that the average VIF value of 4.70 was below the widely used critical value of 10.

**[Insert Tables 2A and 2B here]**

**5. Results**

First, we present the results of the relationship between firms’ position in the network and the firms’ performance. In the next section (3.2) we remove all firms headquartered in China (for our purposes, includes Taiwan, Macao, and Hong Kong) and rebuild the global supply chain network to assess the relationship between firms’ position in the network and firms’ performance. This will highlight how the elimination of China from the supply chain might affect the relationship of network centrality on a firm’s performance.

*5.1 Ordinary Least Squares (OLS) results including China as a Supplier*

We begin the analysis by presenting OLS results for all suppliers including China with accounting return on equity (ROE) as our dependent variable. The results of the single-equation estimation are reported in Table 3. Parameter estimates are given along with standard errors in parentheses; the corresponding robust p-values that account for heteroscedasticity is signified as \*\*\* for p<0.01, \*\* for p<0.05, \* for p<0.1. Table 3 panel A includes only the centrality measures as explanatory variables while Panel B includes the firm’s size as an additional explanatory variable.

**[Insert Table 3 about here]**

Table 3, Panel A, shows that the return on equity is significantly positively associated with *EIG* and *IDG* indicating that improvements in a firm’s in-degree and eigenvector are positively related to a firm’s performance. Based on these results, one could argue that a firm’s performance is a function of both the number of notable suppliers (*IDG*) and the firm’s importance within the supply chain network of suppliers and customers (*EIG*). The negative and significant estimated coefficient on the *ECC* (i.e., *β3*), *ODEG* and *CSZ* seem to indicate that accounting return is negatively affected when the firm is more embedded across the industry and the more dependent it is on notable customers. A similar result holds for Panel B when we control for a firm’s size by including it as an explanatory variable.

Before we proceed further, we employ two tests to ensure that our model is robust to the underlying assumptions. First, we employ the link test to verify that there is no specification error in the dependent variable. The un-tabulated results of our link test[[3]](#footnote-3) with hatsq’s p-value is 0.999 suggest that there is no specification error in the dependent variable. This confirms that there is no misspecification of the accounting return (conditional on the specification). Second, we statistically test if we have any omitted variables using the RAMSEY reset test. The p-value is 0.8580 and hence the null hypothesis that there are no omitted variables cannot be rejected. The link test and reset test thus gives added confidence about our model’s overall specification.

Table 4 reports the OLS results for all suppliers including China with Tobin’s Q as the dependent variable. Similar to the results obtained above, we find that *EIG* and *IDG* are positively associated with the firm’s Tobin’s Q with *p-*values of less than 0.05. Furthermore, *ECC* and *ODG* are negatively significant with Tobin’s Q in three out of four cases with *p-*values of less than 0.05.

*5.2 Ordinary Least Squares (OLS) results excluding China as a Supplier*

The primary focus of our study is the effect on the firm’s profitability when China (and other Far East countries namely Hong Kong, Macau, and Taiwan; hereinafter we denote this as China) is excluded from the supply chain network. We, therefore, recalibrate the centrality measures by excluding China from the supply chain network. The statistical results in Tables 5 and 6 are glaring. First, we note that the variable *EIG*, while positively associated with ROE, is barely significant at a p-value of 0.10. Moreover, EIG is not found to have a significant effect on Tobin’s Q. Second, *ECC* drops out of significance altogether. Third, *IDEG* continues to be positively associated with both accounting return (Table 5) and Tobin’s Q (Table 6). Finally, consistent with our expectation, we find that the coefficient on *PGE* is now negative and statistically significant. When China is excluded, firms are forced to diversify their suppliers but this diversification does not necessarily improve profitability. The negative and significant coefficient on *PGE* implies that in the absence of China, firms may be forced to turn to less complex products in order to maintain and improve firm profitability.

*5.3 Additional Tests*

In this section, we explore whether the main findings are robust to alternative specifications.[[4]](#footnote-4) We conduct several additional tests to ensure our results, in Tables 3 through 6, stand up to further scrutiny to alternative model specifications and variable definitions. For the sake of brevity, we only tabulate the coefficients of the critical variables in Appendix 3. Prior research [see C. Subramaniam (2000)] suggests that CEOs may be more inclined to improve firm performance as measured by Return on Equity (ROE) than other measures of accounting return, such as Return on Capital (ROC) or Return on Assets (ROA). We, therefore, replace ROE by ROC as our dependent variable to investigate if supply chain centrality measures are associated with ROC just as much as they do with ROE. We find that when firms use *ROC*, the results are no different from those reported in table 3 (see Appendix 3, Part I). The estimated coefficient on *EIG* and *IDEG* are positive and significant (coefficient estimates of 17.3 and 0.041 respectively, in Panel A, and significant at the 0.05 and 0.10 level). Similarly, *ECC* and *ODEG* are negative and significant (coefficient estimates of -0.928 and -0.076 respectively in Panel A, and significant at the 0.01 and 0.05 level).

Table 2 illustrates that changes in accounting performance and market performance vary widely across industries. Hence, we perform the analysis again using industry-adjusted accounting and market performance variables.[[5]](#footnote-5) When we exclude China from the supply chain mix, we find that coefficients of *EIG* and *ECC* are no longer significant in three out of four cases whether we use industry-adjusted ROA or industry-adjusted Tobin’s Q. More crucially, the coefficient on *PGE* continues to be negative and significant in three out of four cases (see Appendix 3, Parts III, and IV). Thus, our main findings did not change; in other words, *EIG* and *INDEG* continue to be positive and significant at the 0.05 level, when China is included in the supply chain. However, when China is excluded, *PGE* remains negative and significant. The hypotheses parameters remain positive and significant for *IDEG*, while *PGE* and *CSZ* remain negative and significant through most of these robustness tests, thereby supporting our central tenet that when China is no longer a supplier, firms maintain their profitability by manufacturing less complex goods.

**6. Discussion of the Findings**

Several theories and views have been utilized in the field of global operations including transaction cost analysis, resource-based view, knowledge-based view, strategic choice theory, agency theory, institutional theory, system theory, and network perspective (Lavassani, Movahedi, and Kumar, 2008). The present study views global operations from a network perspective and applies network science techniques to the study of global supply chains. Few studies have attempted to explore the effect of removing select actors from the global supply chain in order to investigate changes in the structure of the network. Büttner, Krieter, Traulsen, and Traulsen (2013) is an example of such research where the author simulated the effect of removing select nodes in a small regional pork supply chain. Büttner et al. (2013) explore the role of various centrality measures on the supply chain risk exposure to disruptions due to trade restrictions, medical reasons, or other related factors. To the best of the knowledge of the authors of this work, the present work is the first global-scale simulation of global supply chain ruptures across multiple tiers of the supply chain. The discussion of findings of the full-scale global supply chain, supply chain without China, and comparisons are presented here.

The location of the firm across the five tiers of the backward supply chain was not found to have a significant effect on the firms’ performance. In the analysis of the global supply chain network, one of the interesting findings was about the role of in-degree versus out-degree. While the in-degree centrality is positively related to the firms’ performance, the out-degree centrality has a negative effect on firms’ performance. This means firms with more suppliers and fewer customers have better financial performance. This could be a characteristic of a manufacturer of final (or closer to final) product where several original part manufacturers are supplying the parts to be assembled into a product that will be supplied to a small number of distributors and wholesalers, potentially with an added value of the brand (versus parts which mostly have the characteristics of a commodity). A surprising result was associated with eccentricity. We hypothesized that firms positioned on longer connected supply chains will have higher financial performance. However, the result suggested otherwise. We believe this is due to the conceptual inverse relationship between eccentricity and vertical integration. One of the novel findings of this study is that more vertically integrated firms have lower eccentricity centrality which enables them to capture greater value in their operation and hence have higher levels of financial performance. We believe the negative relationship between cluster size and firms’ performance can also be explained by the fact that firms with are less vertically integrated belong to larger clusters of collaborative firms and as a result, these firms are sharing the added value with other firms in their cluster. This results in lower firms’ performance. As expected higher levels of eigenvector centrality as they are more associated with more influential firms in the supply chain which provides further support to the application of this measure in the literature.

In the simulation, China was removed and the network structure was reconstructed with the assumption that the remaining connection will handle the global supply chain in the short-term. This assumption is realistic as it may not be feasible for the global supply chain to immediately implement significant changes. In the simulation, while in-degree exhibited a positive effect on the firms’ performance, out-degree was not found to significantly influence the firms’ performance. Eigenvector only showed a positive impact on ROA. Page rank centrality was found to have a significant negative impact on the firms’ performance. This is quite an interesting finding. As per discussions before the page rank can be viewed as the “global” (versus “local”, in the network science term) measure of in-degree as (unlike in-degree) it takes into account the incoming connections of the whole network. The analysis of page rank indicates that firms with a higher degree of deep decencies to the global supply chain will have a worse financial performance when China is removed from the global supply chain. The next notable finding in the simulation was concerning the clustering coefficient. We hypothesized that if a firm is part of a highly connected group of firms it is expected to have better performance as it creates more stability. However, as China plays an important role in the global supply chain its elimination had such a magnitude that its elimination results in a negative relationship between the clustering coefficient and q ratio. The cluster size was also found to affect the firms’ performance negatively due to the lower level of vertical integration in firms operating in large clusters.

**7. Conclusion and Contributions**:

This study has three main contributions. First, it provides a benchmark for manufacturing firms and distributors around the world operating in the post-COVID-19 business environment to better understand the relationship of their supply chain strategy and firms’ financial performance. Second, investors and asset managers can evaluate their portfolios in light of the changing relationship as a result of possible protectionism initiatives. Finally, policymakers can apply the research methodology of this work in various industries while reevaluating post-COVID19 international relations and trades policies at the firm, industry, and country levels.

Policymakers working on global connection can utilize the outcome of this research to explore the consequences of local and global policies on trade patterns, organizational performance as well as individuals’ movements. Another implication of this study for policymakers is that it provides a powerful tool to launch or combat the global ruptures, including trade wars and natural disasters stemming from natural events (e.g. climate change) and human-made events (e.g. wars, supply-chain interruptions, sanctions). For example, using our findings, strategists and policymakers can design high-accuracy offensive and defensive strategies during the disasters, trade-wars and counter-terrorism events, not only at the country level and industry level but also at the firm level and individual level. Changes in business ecosystem patterns can help national, regional, and local agencies to explain and plan for the trends in global and regional and better manage inequality in wealth distribution and employment. This project will enable business strategists to better manage the risk and interruptions across their global value chain and uncover the most influential actors affecting their global operations. The findings will also provide benchmarks for assessing the role of network centrality of firms and industries on national security. This research enables organizations and policymakers to more effectively identify the innovation hubs across at a global scale using big data (c.f. Aksenova et al. 2019). The result of this study will uncover patterns of knowledge and the impact of technology that crosses industries and borders.

**8. Limitations and Directions for Future Studies**

One of the limitations of this study is access to supply chain data. While small and medium private firms do not publish data about their supply chain the role of these firms in supply chain networks is only identified when they have trade with publically traded firms. The data is only from notable customers and suppliers however, this is the only level of data firms are willing to publically release. Additionally, firms do not disclose data about the value of their transitions with customers and suppliers; as a result, the edges in our global supply chain network in the analysis are treated as having equal weights. While these limitations cannot be addressed in the foreseeable future it is important to identify such shortcomings.

Another limitation of this study is that we are assuming ceteris paribus conditions when simulating the models after the elimination of China from the global supply chain. That is, we assume in the short-term the financial performance of the firms remaining in the model stays the same, and only the network centrality characteristics chance. It can be argued that other exogenous factors –beyond the network centrality measures– can influence the financial performance of the firms. For example, while the elimination of a cluster of firms may not significantly change the structure and characteristics of the remaining supply chain network in the short-term, however, it is likely to change the supply chain connections in the long-term by creating new connections and eliminating some of the past connections. Future research would be needed to investigate how such a relationship can change in the new business environment. This can be a fruitful topic for future studies.

This research is conducted in the early months of the global pandemic as a result of COVID-19. The scope and magnitude of the short-term and long-term effects of the pandemic are not clear at the moment. Future studies conducted in the years to come can provide a more comprehensive analysis of the changes in global supply chains. While our data was collected in the early weeks of 2020 it provides a picture of the supply chain map before pandemic affects the supply chain structures considering the data has approximately one financial quarter lag. Future research in the future is vital to explore how the firms have changed their global operation strategy in two years or five years.

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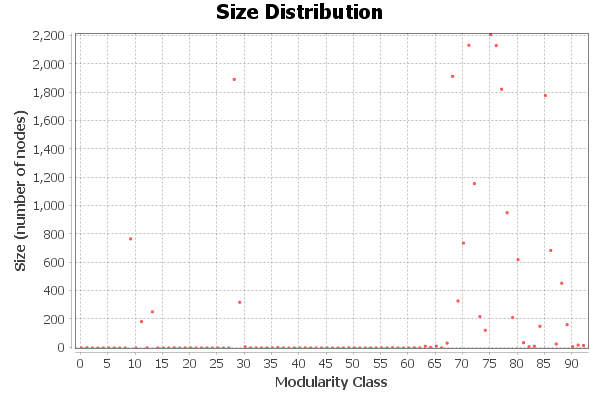
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**Appendices**

**Appendix 1: Size of the communities of firms: 5 tiers of backward supply chain for medical equipment**

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|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Appendix 2: Industry Composition and Distribution of Firms Headquarters** | | | | |
| Top Six Industries | Number of Edges |  | Top Six Firms' Headquartered in | Number of Edges |
| Computer Programming & Data Processing | 10559 |  | U.S.A | 52108 |
| Motor Vehicles and Car Bodies | 9225 |  | China\* | 22752 |
| Semiconductors and Related Devices | 8740 |  | Japan | 19709 |
| Prepackaged Software | 8246 |  | India | 10844 |
| Motor Vehicle Parts and Accessories | 6363 |  | South Korea | 8112 |
| Pharmaceautical Preparations | 5513 |  | Germany | 6992 |
| Total | 48646 |  | Total | 120517 |
|  |  |  |  |  |
| \*Includes Taiwan (9696 edges), and Hong Kong (1349 edges). | | | | |

**Appendix 3**

**Robustness checks on alternative model specifications and variable definitions**

All regressions include the same control variables as those used in Tables 3 through 6, but the coefficients on these control variables are not tabulated. The symbols \*\*\*, \*\*, \*, denote significance at the 1%, 5% and 10% levels, respectively.

**Part I: Using firm's average accounting return (replication of results of Table 3)**

1. Using Return on Capital (*ROC*) instead of *ROE* as a measure of accounting return (N=2,826).

*EIG ECC IDEG ODEG CSZ*

*Panel A*  17.258\* -0.928\*\*\* 0.041\*\* -0.076\*\* -0.001\*\*

*Panel B*  15.449\* -0.878\*\*\* 0.067\*\*\* -0.082\*\* -0.001\*\*

**Part II: Using firm's average market return (replication of results of Table 4)**

1. Using stock return (*MKRTN*) instead of Tobin's Q (*TBQ*) as a measure of firm's market return (N=3,816).

*EIG ECC IDEG ODEG CSZ*

*Panel A*  49.44\* 0.638 0.035 0.075 0.000

*Panel B*  191.759\*\*\* -0.750 0.430\*\*\* 0.032 -0.000

**Part III: Using firm's industry-average return (replication of results of Table 5)**

1. Using industry-adjusted Return on Assets (*A\_ROA*) instead of firm’s *ROE* as a measure of accounting return (N=2,545).

*EIG ECC PGE IDEG ODEG CSZ*

*Panel A*  1.422 0.060 -2252.88\*\* 0.012 -0.001-0.001\*\*

*Panel B*  1.438 0.013 -1957.42\*\* 0.030\*\*\* -0.013 -0.001\*\*

**Part IV: Using firm's industry-average return (replication of results of Table 6)**

1. Using industry-adjusted Tobin's Q (*A\_TBQ*) instead of firm’s Tobin's Q (*TBQ*) as a measure of firm's market return (N=3,179).

*EIG ECC PGE IDEG ODEG CSZ*

*Panel A*  0.574 -0.022 -405.05\* 0.012\*\*\* -0.004 -0.001\*\*\*

*Panel B*  0.613 -0.044\*\* -278.11 0.020\*\*\* -0.009\*\* -0.001\*\*\*

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 1: Degree & Tier Correlation Table

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Correlation | Degree | In-degree | Out-degree | The ratio of In/Out degree |
| Weighted Tier | -0.1 | 0.08 | -0.17 | -0.16 |

# **TABLE 2**

# Distribution of Firm-Year Observations Across Industries\* and Median Values of Main Variables

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Fama & French**  **Industry Classification** | **Num** | **ROE** | **CLS** | **EIG** | **ECC** | **ATH** | **PGE** | **IDG** | **ODG** | **CLT** | **CSZ** | **TIR** |
| IND1: NoDur | 236 | 10.21 | 0 | 0 | 13.81 | 0 | 0 | 3.5 | 3.27 | 0.01 | 1211.75 | 4.72 |
| IND2: Durbl | 340 | 8.45 | 0 | 0.01 | 13.5 | 0 | 0 | 6.39 | 9.52 | 0.03 | 1694.55 | 4.6 |
| IND3: Manuf | 871 | 9.07 | 0 | 0.01 | 13.86 | 0 | 0 | 4.47 | 6.44 | 0.02 | 1526.81 | 4.6 |
| IND4: Enrgy | 168 | 6.83 | 0 | 0 | 14.05 | 0 | 0 | 7.77 | 4.3 | 0.02 | 1758.32 | 4.77 |
| IND5: Chems | 191 | 10.47 | 0 | 0 | 13.8 | 0 | 0 | 5.7 | 4.83 | 0.01 | 1552.96 | 4.56 |
| IND6: BusEq | 838 | 9.15 | 0 | 0.02 | 13.77 | 0.01 | 0 | 6.11 | 8.26 | 0.02 | 1737.61 | 4.48 |
| IND7: Telcm | 97 | 9.77 | 0 | 0.01 | 13.79 | 0 | 0 | 7.76 | 4.52 | 0.01 | 1689.82 | 4.73 |
| IND8: Utils | 21 | 11.39 | 0 | 0 | 14.33 | 0 | 0 | 3.71 | 2.29 | 0.01 | 1611.86 | 4.92 |
| IND9: Shops | 227 | 8.62 | 0 | 0.01 | 13.95 | 0 | 0 | 6.83 | 4.44 | 0.01 | 1455.37 | 4.61 |
| IND10: Hlth | 230 | 10.07 | 0 | 0 | 13.33 | 0 | 0 | 9.2 | 5.78 | 0.01 | 1228.05 | 3.74 |
| IND11: Money | 26 | 7.75 | 0 | 0 | 14.08 | 0 | 0 | 4.04 | 3.77 | 0 | 1613.69 | 4.6 |
| IND12: Other | 494 | 9.07 | 0 | 0 | 14.04 | 0 | 0 | 4.11 | 5.02 | 0.01 | 1445.33 | 4.65 |
| **Overall** | **3739** | **9.13** | **0** | **0.01** | **13.81** | **0** | **0** | **5.63** | **6.31** | **0.01** | **1552.99** | **4.55** |

**\* Notes:**

1 NoDur Consumer Nondurables -- Food, Tobacco, Textiles, Apparel, Leather, Toys: 0100-0999, 2000-2399, 2700-2749, 2770-2799, 3100-3199, 3940-3989.

2 Durbl Consumer Durables -- Cars, TVs, Furniture, Household Appliances: 2500-2519, 2590-2599, 3630-3659, 3710-3711, 3714-3714, 3716-3716, 3750-3751, 3792-3792, 3900-3939, 3990-3999

3 Manuf Manufacturing -- Machinery, Trucks, Planes, Off Furn, Paper, Com Printing: 2520-2589, 2600-2699, 2750-2769, 3000-3099, 3200-3569, 3580-3629, 3700-3709, 3712-3713, 3715-3715, 3717-3749, 3752-3791, 3793-3799, 3830-3839, 3860-3899

4 Enrgy Oil, Gas, and Coal Extraction and Products: 1200-1399, 2900-2999

5 Chems Chemicals and Allied Products: 2800-2829, 2840-2899

6 BusEq Business Equipment-Computers, Software, and Electronic Equipment: 3570-3579, 3660-3692, 3694-3699, 3810-3829, 7370-7379

7 Telcm Telephone and Television Transmission: 4800-4899

8 Utils Utilities: 4900-4949

9 Shops Wholesale, Retail, and Some Services (Laundries, Repair Shops): 5000-5999, 7200-7299, 7600-7699

10 Hlth Healthcare, Medical Equipment, and Drugs: 2830-2839, 3693-3693, 3840-3859, 8000-8099

11 Money Finance: 6000-6999

12 Other -- Mines, Constr, BldMt, Trans, Hotels, Bus Serv, Entertainment

**Source:** Fama French Industry classification:[https://mba.tuck.dartmouth.edu/PGEs/faculty/ken.French/Data\_Library/det\_12\_ind\_port.html](https://mba.tuck.dartmouth.edu/pages/faculty/ken.French/Data_Library/det_12_ind_port.html)

**Table 2A**

**Descriptive Statistics**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable | Obs | Mean | Std. Dev. | Min | Max |
| ROE | 3739 | 9.13 | 8.27 | -4.00 | 23.32 |
| CLS | 3739 | 0.00 | 0.00 | 0.00 | 0.00 |
| EIG | 3739 | 0.01 | 0.04 | 0.00 | 1.00 |
| ECC | 3739 | 13.81 | 0.71 | 13.00 | 15.00 |
| ATH | 3739 | 0.00 | 0.03 | 0.00 | 1.00 |
| PGE | 3739 | 0.00 | 0.00 | 0.00 | 0.01 |
| IDG | 3739 | 5.63 | 8.92 | 0.00 | 27.00 |
| ODG | 3739 | 6.31 | 6.25 | 1.00 | 20.00 |
| CLT | 3739 | 0.01 | 0.02 | 0.00 | 0.07 |
| CSZ | 3739 | 1552.99 | 551.16 | 687.00 | 2277.00 |
| TIR | 3739 | 4.55 | 0.50 | 1.00 | 5.00 |
|  | | | | | |

**Table 2B**

**Pairwise correlations**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| (1) CLS | 1.000 |  |  |  |  |  |  |  |  |  |
| (2) EIG | 0.030 | 1.000 |  |  |  |  |  |  |  |  |
| (3) ECC | 0.010 | -0.225\* | 1.000 |  |  |  |  |  |  |  |
| (4) ATH | 0.011 | 0.863\* | -0.107\* | 1.000 |  |  |  |  |  |  |
| (5) PGE | -0.002 | 0.473\* | -0.194\* | 0.499\* | 1.000 |  |  |  |  |  |
| (6) IDG | -0.012 | 0.272\* | -0.385\* | 0.229\* | 0.485\* | 1.000 |  |  |  |  |
| (7) ODG | 0.078\* | 0.395\* | -0.502\* | 0.164\* | 0.218\* | 0.343\* | 1.000 |  |  |  |
| (8) CLT | 0.055\* | 0.048\* | -0.177\* | -0.030 | -0.023 | 0.044\* | 0.376\* | 1.000 |  |  |
| (9) CSZ | 0.129\* | 0.160\* | -0.061\* | 0.064\* | -0.006 | 0.047\* | 0.215\* | 0.106\* | 1.000 |  |
| (10) TIR | 0.598\* | -0.123\* | 0.339\* | -0.035 | -0.107\* | -0.222\* | -0.223\* | -0.020 | 0.033 | 1.000 |
| *\*\*\* p<0.01, \*\* p<0.05, \* p<0.1* | | | | | | | | | | |

**Table 3: Regression results including China: Dependent Variable is ROE**

|  |  |  |
| --- | --- | --- |
|  | (1) | (2) |
|  |  |  |
| CLS | 8.788e+08 | 8.736e+08 |
|  | (3.227e+09) | (3.227e+09) |
| EIG | 18.76\*\* | 18.613\*\* |
|  | (7.692) | (7.724) |
| ECC | -.824\*\*\* | -.821\*\*\* |
|  | (.232) | (.232) |
| ATH | -12.238 | -12.017 |
|  | (10.118) | (10.149) |
| PGE | 453.837 | 458.267 |
|  | (298.001) | (298.432) |
| IDG | .053\*\*\* | .054\*\*\* |
|  | (.018) | (.019) |
| ODG | -.072\*\* | -.073\*\* |
|  | (.03) | (.03) |
| CLT | -2.583 | -2.429 |
|  | (5.946) | (5.969) |
| CSZ | -.002\*\*\* | -.002\*\*\* |
|  | (0) | (0) |
| TIR | .445 | .457 |
|  | (.378) | (.38) |
| LOGSZ |  | -.016 |
|  |  | (.05) |
| \_cons | 18.733\*\* | 18.801\*\* |
|  | (8.076) | (8.084) |
| Observations | 3739 | 3739 |
| R-squared | .024 | .024 |
| *Standard errors are in parentheses* | | |
| *\*\*\* p<.01, \*\* p<.05, \* p<.1* | | |
|  | | |

**Table 4: Regression results including China: Dependent Variable is Q-Ratio**

|  |  |  |
| --- | --- | --- |
|  | (1) | (2) |
|  |  |  |
| CLS | -7.204e+08 | -7.533e+08 |
|  | (4.803e+08) | (4.689e+08) |
| EIG | 2.875\*\*\* | 2.14\*\* |
|  | (.971) | (.954) |
| ECC | -.108\*\*\* | -.095\*\*\* |
|  | (.03) | (.029) |
| ATH | -1.862 | -.876 |
|  | (1.154) | (1.144) |
| PGE | 11.642 | 34.988 |
|  | (51.288) | (52.43) |
| IDG | .005\*\* | .014\*\*\* |
|  | (.002) | (.002) |
| ODG | -.006 | -.007\*\* |
|  | (.004) | (.004) |
| CLT | -1.935\*\*\* | -1.167\* |
|  | (.717) | (.696) |
| CSZ | 0\*\*\* | 0\*\*\* |
|  | (0) | (0) |
| TIR | -.211\*\*\* | -.154\*\*\* |
|  | (.052) | (.051) |
| LOGSZ |  | -.08\*\*\* |
|  |  | (.006) |
| \_cons | 6.199\*\*\* | 6.507\*\*\* |
|  | (1.199) | (1.171) |
| Observations | 3815 | 3815 |
| R-squared | .041 | .083 |
| *Standard errors are in parentheses* | | |
| *\*\*\* p<.01, \*\* p<.05, \* p<.1* | | |
|  | | |

**Table 5: Regression results excluding China: Dependent Variable is ROE**

|  |  |  |
| --- | --- | --- |
|  | (1) | (2) |
|  |  |  |
| CLS | .187 | .127 |
|  | (1.884) | (1.886) |
| EIG | 9.901\* | 9.931\* |
|  | (5.961) | (5.965) |
| ECC | .222 | .208 |
|  | (.157) | (.158) |
| ATH | 3.672 | 3.99 |
|  | (12.156) | (12.129) |
| PGE | -4026.321\*\* | -3951.122\*\* |
|  | (1879.766) | (1880.408) |
| IDG | .101\*\*\* | .106\*\*\* |
|  | (.026) | (.026) |
| ODG | -.014 | -.018 |
|  | (.034) | (.035) |
| CLT | -4.037 | -3.611 |
|  | (6.385) | (6.407) |
| CSZ | -.003\*\* | -.003\*\* |
|  | (.001) | (.001) |
| TIR | .198 | .23 |
|  | (.386) | (.389) |
| LOGSZ |  | -.045 |
|  |  | (.054) |
| \_cons | 5.812\* | 6.263\*\* |
|  | (2.99) | (3.05) |
| Observations | 3105 | 3105 |
| R-squared | .015 | .015 |
| *Standard errors are in parentheses* | | |
| *\*\*\* p<.01, \*\* p<.05, \* p<.1* | | |
|  | | |

**Table 6: Regression results excluding China: Dependent Variable is Q-Ratio**

|  |  |  |
| --- | --- | --- |
|  | (1) | (2) |
|  |  |  |
| CLS | -.167 | -.27 |
|  | (.237) | (.233) |
| EIG | .751 | .794 |
|  | (.789) | (.759) |
| ECC | -.008 | -.033\* |
|  | (.02) | (.02) |
| ATH | 1.312 | 1.78 |
|  | (2.086) | (2.152) |
| PGE | -950.484\*\*\* | -810.055\*\*\* |
|  | (219.85) | (218.044) |
| IDG | .014\*\*\* | .023\*\*\* |
|  | (.003) | (.003) |
| ODG | .002 | -.004 |
|  | (.004) | (.004) |
| CLT | -2.13\*\*\* | -1.343\* |
|  | (.735) | (.715) |
| CSZ | -.001\*\*\* | -.001\*\*\* |
|  | (0) | (0) |
| TIR | -.307\*\*\* | -.248\*\*\* |
|  | (.049) | (.048) |
| LOGSZ |  | -.082\*\*\* |
|  |  | (.006) |
| \_cons | 3.572\*\*\* | 4.368\*\*\* |
|  | (.379) | (.376) |
| Observations | 3179 | 3179 |
| R-squared | .058 | .102 |
| *Standard errors are in parentheses* | | |
| *\*\*\* p<.01, \*\* p<.05, \* p<.1* | | |
|  | | |

1. Industries, and firms here are counted based on their number of contribution across the 5 tiers. [↑](#footnote-ref-1)
2. For details see [https://mba.tuck.dartmouth.edu/PGEs/faculty/ken.French/Data\_Library/det\_12\_ind\_port.html](https://mba.tuck.dartmouth.edu/pages/faculty/ken.French/Data_Library/det_12_ind_port.html) [↑](#footnote-ref-2)
3. Results available upon request. [↑](#footnote-ref-3)
4. See Appendix 3 for details. All of our sensitivity results, in full, are available upon request. [↑](#footnote-ref-4)
5. We compute this by taking the difference between firms’ accounting (market) returns and the median accounting (market) returns for all companies in the firm’s same Fama-French industry classification. [↑](#footnote-ref-5)