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The Logistics of Supply Chain Alpha

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Gleaning alpha from the supply chain networks

Unstructured supply-chain network data

Companies do not exist in isolation but are connected to their customers, suppliers, competitors, and joint ventures. In this novel piece of research, we study the FactSet Revere supply chain database and show how portfolio managers can utilize unstructured customer-supplier data to generate alpha.

The supply chain alpha

Supply chain data is unstructured, incomplete, and highly complex. A single shock at one company may be transmitted to other connected firms. When a subject company raises its earnings guidance (or increases dividends or beats earnings expectations), its suppliers (and to a lesser extent, customers) also tend to benefit. Furthermore, the performance of a company's customers and suppliers is predictive of its own stock returns and fundamentals. We also find that stock selection signals based on supply chain data contain significant alpha.

Social networks and the supply chain

Inspired by algorithms in social networks and Internet searches such as Google PageRank, we analyze the supply chain web network as a whole to unlock a new differentiated alpha source. We follow goods as they move upstream and downstream through the full length of the supply chain. This allows us to identify key suppliers, customers and other companies of systemic importance to the fulfillment process. Our analysis shows that key companies within the supply chain network contain strong alpha on the long side, after controlling for other factors and risk measures.

Source: gettyimages.com

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A letter to our readers

Tracing the Supply Chain

Companies do not exist in isolation but are connected through their supply chain relationships. Treating companies as nodes and their supply chain relationships as directed edges, we see supply chain networks in which goods, value, and information are transmitted from one node to another. Although the concept seems new, the supply chain network has long been a natural ecosystem that a company lives in, depends on, and evolves within. Traditionally, analysis around a company's financial performance has been primarily focused on the company's fundamentals, without much attention given to the supply chain network. For investment managers, the supply chain should be a natural extension of traditional fundamental research.

However, supply chain data is difficult to harness. Firstly, information is often held within the secret confines of a company in order to protect themselves from their competitors, as revealing such information can potentially disrupt the supply chain ecosystem. Therefore, the supply chain network data coverage is moderate even while using the best available data source. Secondly, most information available on a company's supply chain is due to its own voluntary disclosure, which may be biased toward large companies and reputable supply chain partners.

In this report, we leverage a unique dataset that provides over ten years of history on supply chain relationships – the FactSet Revere data, and explore predictive signals using information about a company's upstream suppliers and downstream customers including stock returns, fundamentals, and number of linkages. The results are encouraging as we find that the performance of a company's customers and suppliers is predictive of its own stock returns. We further show that major events from supply chain partners have impacts on a company's stock returns as well.

We argue that the predictive relationships in the supply chain may be long-term sources of alphas. The supply chain data is proprietary, complex, and difficult to analyze, and as such it may take the market time to digest and react appropriately. Second, the lag time effect may not only be due to investors' inattention, but also due to the slow diffusion of companies' operational information to their supply chain partners. Our results are robust as they show that the recent dissimilation of supply chain data has not arbitraged away the performance of such strategies.

We further delve into the multiplicity of supply chains and leverage graph theory such as Google's PageRank algorithm to study the network implications of the supply chain. We find potential alpha opportunities by identifying companies with important network position.

A special thanks to Jing Wu, Ph.D. candidate from the University Of Chicago Booth School Of Business, who has contributed greatly to the content of this report during his summer internship with the quant team. We offer our sincere appreciation for his ideas, expertise, and insight. Some content in this report may be present in his dissertation.

Regards,

Yin, Javed, George, Kevin and the quant team
Deutsche Bank Quantitative Strategy

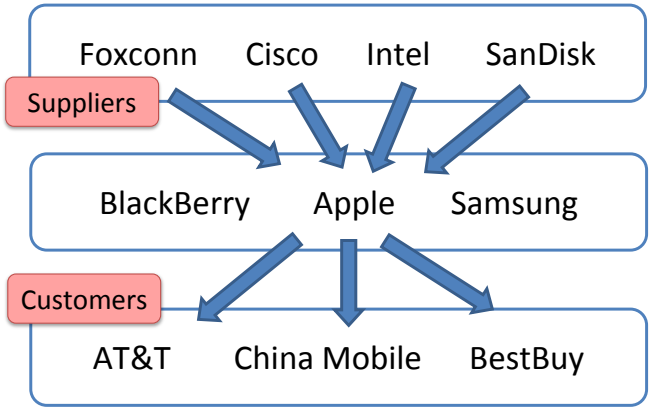
Unstructured Supply Chain Data

Introducing the supply chain network

In this study, we use an interesting database of unstructured supply chain relationship, provided by FactSet[1]. We first walk through the supply chain of Apple as an example to show some key characteristics of supply chain networks (SCN). In general, supply chain networks treat companies as nodes in the network, and their supply chain relationships are treated as directed edges.

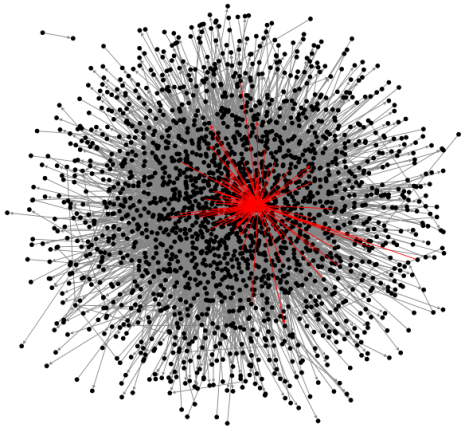
Figure 1 shows some major suppliers and customers of Apple as of June 30, 2014[2]. The suppliers shown in the figure form a significant portion of Apple's COGS (Cost of Goods Sold). Specifically, Foxconn (Hon Hai Precision) is one of Apple's major manufacturing suppliers, as reflected in the "assembled in China" note at the back of every Apple product. Cisco, Intel, and SanDisk are Apple's major part suppliers, as they provide wireless modules, processing units, and flash memory for Apple, respectively. The customers shown in the figure – wireless service providers AT&T and China Mobile, and consumer electronics retailer Best Buy – are among the major contributors of Apple's revenue. Apart from Apple's suppliers and customers, Figure 1 also shows two of Apple's major competitors, BlackBerry and Samsung. It is common that competitors share the same suppliers and customers. We will discuss this strategic competitive interaction later in this paper.

Figure 1: Snapshot of Apple's supply chain



Source: Bloomberg Finance LP, FactSet Deutsche Bank Quantitative Strategy

Figure 2: Apple's position within the US SCN



Source: Bloomberg Finance LP, FactSet, Deutsche Bank Quantitative Strategy

Figure 2 shows Apple's position within the Russell 3000 supply chain network. This layout algorithm places a company in a central position if it has many supplier and customer relationships, and if its suppliers and customers are, themselves, in central positions (Fruchterman and Reingold [1991]). We will discuss different centrality measures adopted from social networks and their implications later in this report.

[1] Please note that this is the data collected by Revere Data, LLC. Factset acquired Revere in 2013. Please see our previous research paper "Uncovering Hidden Economic Links", Cahan, et al [2013] for details of using Revere data.

[2] Note that all cross sectional results in this paper use the snapshot of the supply chain network as of this date.

Figure 2 shows that Apple is very central within the US economy – it not only connects to many other companies, but also, the companies that Apple connects to are well-connected themselves.

Supply chain networks are critical to the fulfillment process of the broader economy for several reasons:

- Important: A shock in the network could disrupt normal operations and cash flows of many closely-related companies. For instance, if Foxconn's operations were suddenly paused or Intel had shipment delays in its products, Apple might not be able to deliver its iPhones to AT&T or China Mobile on time. Note that some of the suppliers are not substitutable, therefore, the reliability of such suppliers are critical to the subject company.
- Complicated: Supply chain networks are complicated for several reasons. First, the network is large-scale and interconnected, as there are tens of thousands of companies and each company has multiple supply chain relationships with others. Second, the information about companies and their supply chain relationships are heterogeneous – companies vary by size, industries, and geographical regions. Third, the supply chain relationships also evolve over time. On one hand, the topology can change over time as both new companies and new connections are formed, and some old companies and existing connections disappear. On the other hand, for the same topology, a company's product offering is always evolving, and the sales to the same customer can vary year from year.
- Incomplete: Supply chain data is often very sensitive information to a company, because of its strategic implications. Using Apple's competitors as an example, since companies in the same industry sector (mobile phone manufacturers in this case) may share the same suppliers and customers, they may not want to disclose that information for fear that the competitors could take advantage of it by disrupting its supply chain partners. This is typically the case for smaller companies with less market power compared to industry giants. As a result, the supply chain network information available to the public is rather sparse and incomplete. It tends to have a bias toward larger-cap companies as they are less apt to protect such information, and also because they are under constant market scrutiny. Even using the best data source for cross-sectional coverage[3], the supply chain data covers only about 50% of all public listed companies in the US, and less than 20% of the total revenue of those covered companies.
- Systematic/systemic: Supply chain network is a source for systematic risk and a network shock can be systemic. Unlike financial hedging and diversification, it is difficult or even impossible for companies to hedge their operational risk. Using Apple's example again, Foxconn, whose factories are mostly located in China, may be the only company on earth with the manufacturing capability or capacity for Apple's popular products. Therefore, any shock to Foxconn is systematic to Apple. Second, supply chain network risk can also be systemic, as a single shock can trigger aggregate fluctuation. A good example is the auto industry bailout during the 2008 financial crisis, where Ford Motor Co. asked the US government to bailout its major competitor, GM Corp, because GM's shutdown would have pushed their common suppliers to bankruptcy, adversely affecting Ford. In this case, a shock to GM Corp is at least a systemic shock to

[3] Bloomberg has a very good cross-sectional coverage of supply chain data, but we are not able to obtain historical point-in-time data.

the whole auto industry in the US, with possible contagion to other industries and the whole economy (luckily it did not happen). Recent academic research in financial economics also reaffirms the viewpoint that idiosyncratic shocks in supply chain networks are the sources for aggregated fluctuations in the economy. (see Acemoglu, et al, [2012], Kelly, et al, [2013]).

The data we use for this study is FactSet Revere – the supply chain relationships, which has had coverage from April 2003 onward. FactSet captures two kinds of supply chain relationships, with actual sales and without actual sales.

For the relationships with sales, FactSet collects such information from publicly-listed companies' 10-K fillings. According to SEC's Statement of Financial Accounting Standards No. 14 (SFAS 14), "if 10% or more of the revenue of an enterprise is derived from sales to any single customer, that fact and the amount of revenue from each such customer shall be disclosed" in interim financial reports issued to shareholders. However, 10% is a very high threshold, and the majority of supply chains do not exceed that threshold. For example, Apple does not disclose any customer companies in its 10-K fillings as none of them exceeds 10% of Apple's revenue. In terms of the number of observations in this category, there are about 1,000 such relationships disclosed in 10-K per year, out of 5,000 to 6,000 public companies. If we only used the 10-K as a source of data, then we would have a very sparse supply chain network.

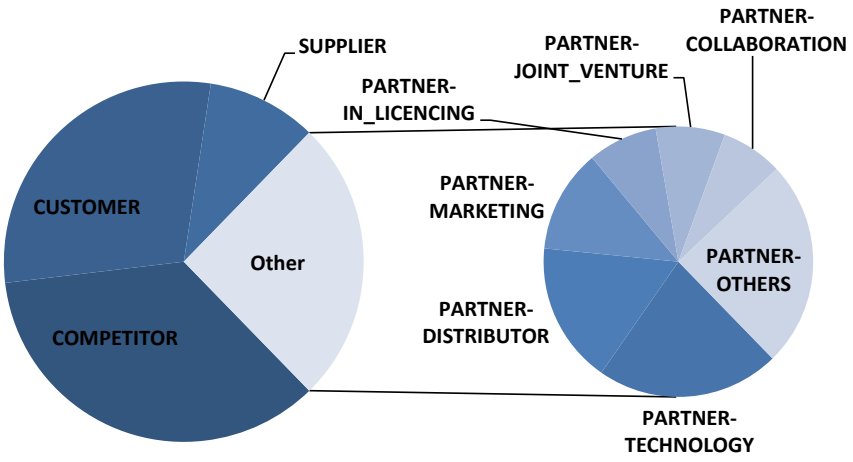
A better and more complete picture of the actual supply chain network can be obtained using relationships without the actual sales. For those relationships, FactSet captures them from much wider sources, e.g., companies' conference call transcripts, capital market presentations, company press releases, company websites, etc. There are about 25,000 such relationships without actual sales captured by FactSet per year.

The FactSet Revere data are all point-in-time[4], meaning that there is a specific date in which the data is updated. FactSet monitors a company's 10-K filing, investor presentations, and websites on an annual basis, while a company's press releases and corporate actions are monitored daily.

Apart from the supply chain relationships, FactSet also captures other relationships in the natural supply chain ecosystem, as is shown in Figure 3. Supplier and customer relationships account for 1/3 of total relationship observations. Competitor relationship, which account for about 1/3 of all observations, is another major relationship reported voluntarily by companies in their financial reports and other documents.

[4] The importance of having true point-in-time data in quantitative research and backtesting is discussed in our previous research, see Wang, et al [2014b].

Figure 3: Types of supply chain relationships captured



Source: Bloomberg Finance LP, FactSet, Deutsche Bank Quantitative Strategy

Strategic partner relationship, which accounts for the remaining 1/3 of relationships, is defined more granularly:

- In-licensing: The relationship company from whom the subject company licenses products, patents, intellectual property or technology – the "opposite" of an Out-licensing relationship.
- Out-licensing: The relationship company to which the subject company licenses products, patents, intellectual property or technology, where the subject company is paid by the relationship company, commonly upfront and through periodic future payments.
- Manufacturing: The relationship company which provides paid manufacturing services to the source company.
- Marketing: Entities which provide paid marketing and/or branding/advertising services to the subject company.
- Distribution: The relationship company to which the subject company pays to distribute its products/services.
- Equity Investment: The relationship company in which the subject company owns equity stake – the "opposite" of an Investors relationship.
- Investment: The relationship company which owns equity stake in the subject company.
- Joint Venture: The subject company jointly owns a separate company with one or more relationship companies.
- Integrated Product Offering: The relationship company with whom the subject company agrees to bundle standalone products/services of each company,

which are marketed together as one offering. No money is exchanged upfront, and costs, risks and profits are shared.

- Research Collaboration: The relationship company collaborates with the subject company for research and development, generally for new product development – common between science companies and between technology companies.

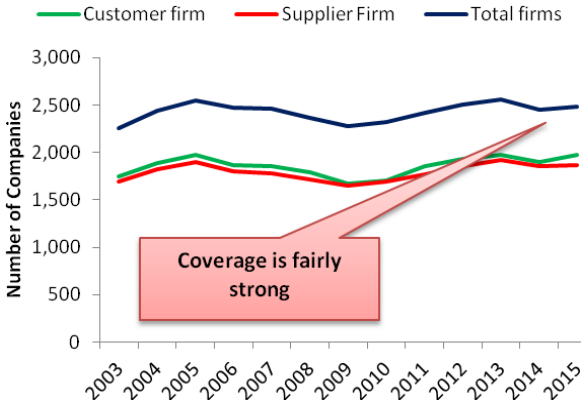
Analyzing the dataset

FactSet Revere currently covers more than 16,000 publicly-traded global companies, with historical data going back to 2003 for US coverage and 2011 for international coverage. Since the history for international companies is limited, we focus our research on US companies in the Russell 3,000 universe.

Figure 4 shows the Russell 3,000 companies with FactSet Revere coverage of supply chain relationships (i.e., with and without sales values). The coverage is fairly strong. About 2,500 companies are shown to have at least one supply chain relationship with another Russell 3,000 company.

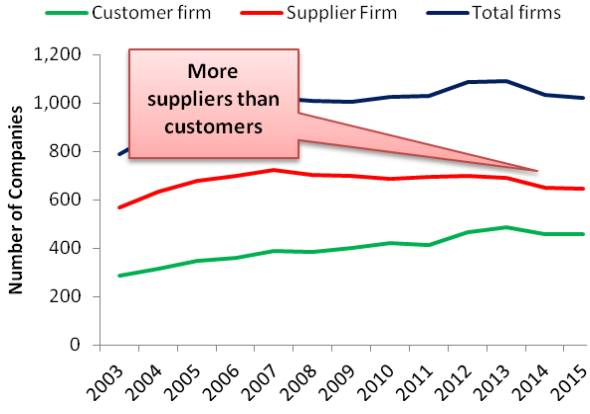
Figure 5 shows the Russell 3,000 coverage for all supply chain relationships with sales value. Regarding the supply chain network constructed by major sales relationships, i.e., the sales are at least 10% of the supplier's revenue, there are more supplier companies than customer companies, resulting in a reverse pyramid-shaped economy. This makes sense intuitively as major customers in the downstream may be large retailers.

Figure 4: FactSet supply chain coverage for all relationships in Russell 3000 universe



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

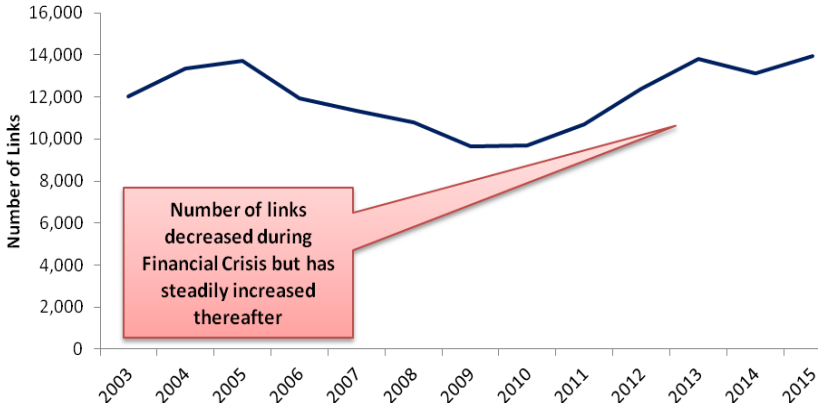
Figure 5: FactSet supply chain coverage for relationships with actual sales in Russell 3000 universe



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 6 shows the number of total relationships captured by the database. We can see that the number of links dipped briefly during the 2008 financial crisis but steadily recovered thereafter. This means that we tend to have a more sparse network in recessions and a more dense network in expansions.

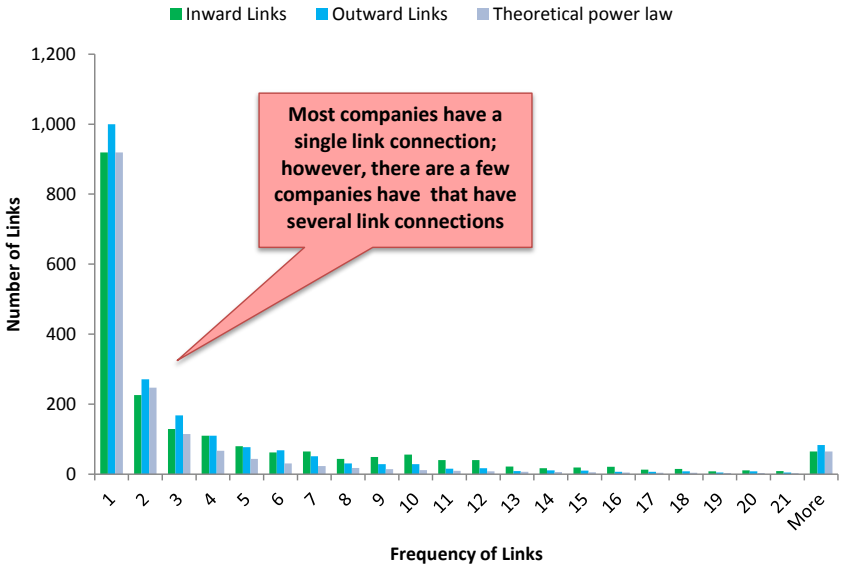
Figure 6: Time series of the total number of links



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 7 shows the distribution of the number of links. Most companies only have a single supply chain relationship. The number of links roughly follows a power law distribution, meaning that the number of companies decreases exponentially as the number of supply chain links increases. This is in line with the common empirical data for a degree distribution (see Clauset, et al. [2009]). However, we can also see a heavy tail on the right end, i.e., there are about 50 companies with an excessively large number of connected relationships, which suggests that the supply chain network is incomplete. The number of firms with only a few supply chain relationships should be less, while the number of firms with many supply chain relationships should be much larger to avoid the fat right tail.

Figure 7: Frequency distribution of the number of links



Source: FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 8 to Figure 10 show the top ten companies ranked by the number of suppliers, the number of customers and the total number of relationships, respectively.

Unsurprisingly, the company with the largest number of suppliers (and also the largest total number of relationships) is Wal-Mart. However, Wal-Mart does not have as many public companies as customers, as it mostly sells to retail consumers directly. Therefore, the supply chain network is generally asymmetric, with different numbers of suppliers and customers. It is highly industry-specific.

Besides, Wal-Mart, GE, IBM, Microsoft and Boeing are well-connected. If we associate the most-connected companies to their industry sector, we immediately notice that those companies primarily belong to two sectors: manufacturing and logistics, including wholesalers, retailers and transportation. This makes sense intuitively, as supply chain networks have to do with the production and distribution of physical goods.

Figure 8: Companies with most suppliers

Company names	# of suppliers
Wal-Mart Inc	202
General Electric Co	136
Boeing Co	129
Verizon Inc	118
Apple Inc	108
AT&T Inc	105
Target Corp	100
Ford Motor Co	99
Hewlett-Packard Co	96
Northrop Grumman	95

Source: Bloomberg Finance LP, FactSet, Deutsche Bank Quantitative Strategy

Figure 9: Companies with most customers

Company names	# of customers
Microsoft Corp	86
IBM	85
General Electric	72
Oracle Corp	71
Standex Corp	67
Walt Disney Co	64
Honeywell Inc	58
Hewlett-Packard Co	56
MISTRAS Group Inc	55
Time Warner Inc	52

Source: Bloomberg Finance LP, FactSet, Deutsche Bank Quantitative Strategy

Figure 10: Companies with most total partners

Company names	# of partners
Wal-Mart Inc	214
General Electric Co	193
IBM	168
Microsoft Corp	156
Boeing Co	152
Hewlett-Packard Co	149
Apple Inc	142
Cisco Systems Inc	139
Verizon Inc	137
AT&T Inc	121

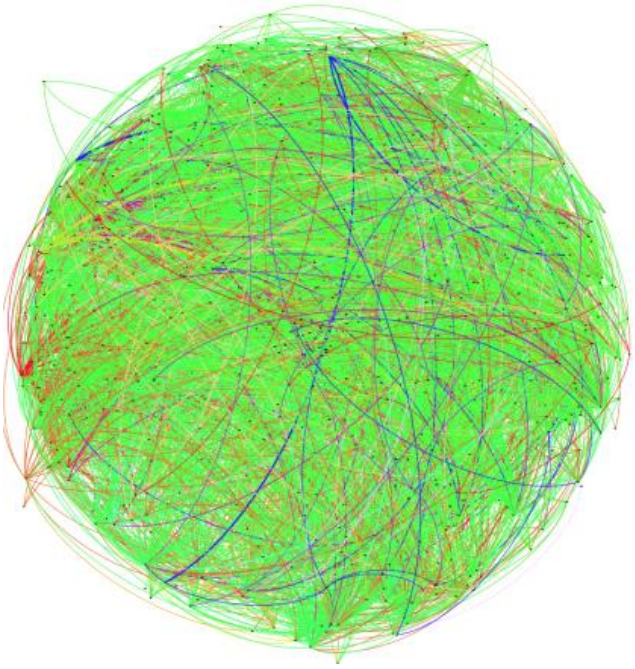
Source: Bloomberg Finance LP, FactSet, Deutsche Bank Quantitative Strategy

Intricacies of the supply chain data

Here we discuss the intricacies of the supply chain data. Since we know the supply chain data is incomplete, it is crucial for us to understand potential systematic biases.

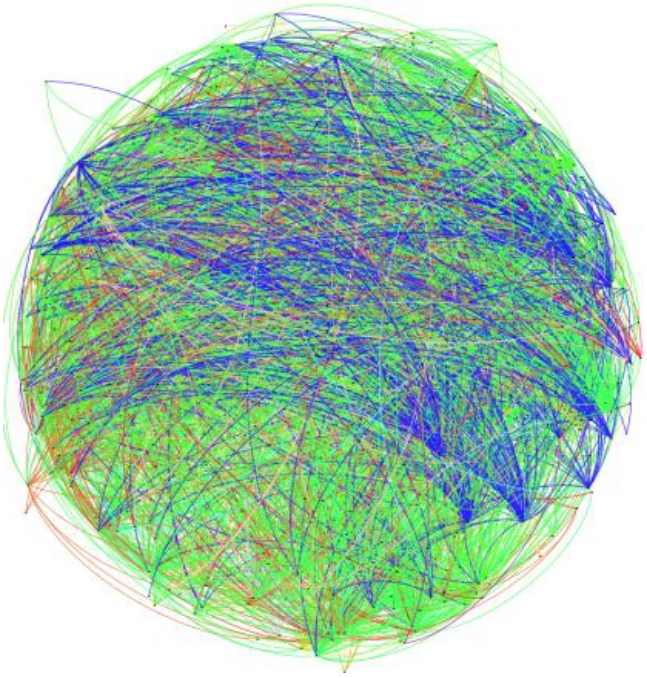
We plot the companies in the S&P 500 universe according to the supplier company's industry sector in Figure 11, and according to the customer company's industry sector in Figure 12. Manufacturing companies are colored in green and logistics companies are colored in blue. As shown, most edges in Figure 11 are green, meaning most supplier companies are related to manufacturing, and most edges in Figure 12 are either green or blue, meaning most customer companies are related to manufacturing and logistics. We need to account for this natural industry bias, which we discuss our investment strategies later.

Figure 11: S&P 500 supply chain network, colored by supplier's industry sector



Source: Bloomberg Finance LP, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

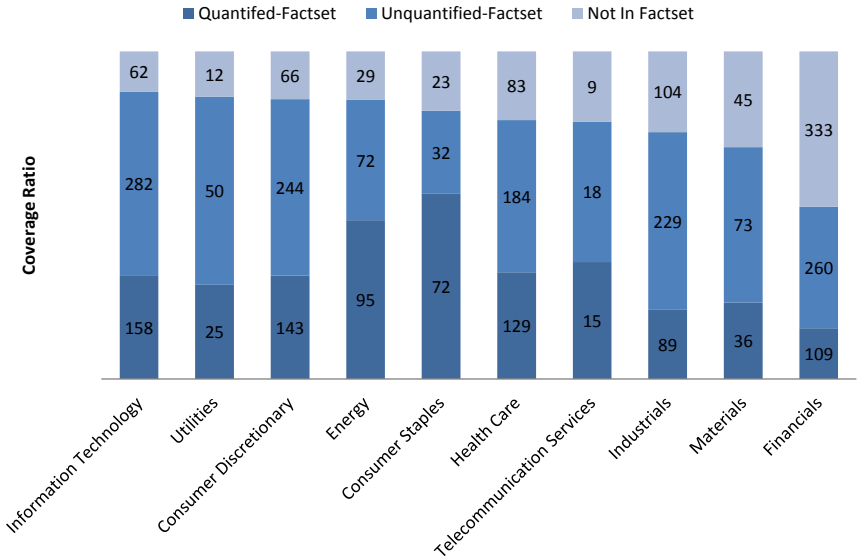
Figure 12: S&P 500 supply chain network, colored by customer's industry sector



Source: Bloomberg Finance LP, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

We also check the company coverage according to sector and industry (Figure 13 Figure 14). As we can see, the coverage is quite even across different sectors. The best-covered sectors include the Information Technology, Utilities, Consumer Discretionary and Energy sectors – more than 85% coverage. The worst-covered sector is the Financial sector, which still has more than 50% of coverage.

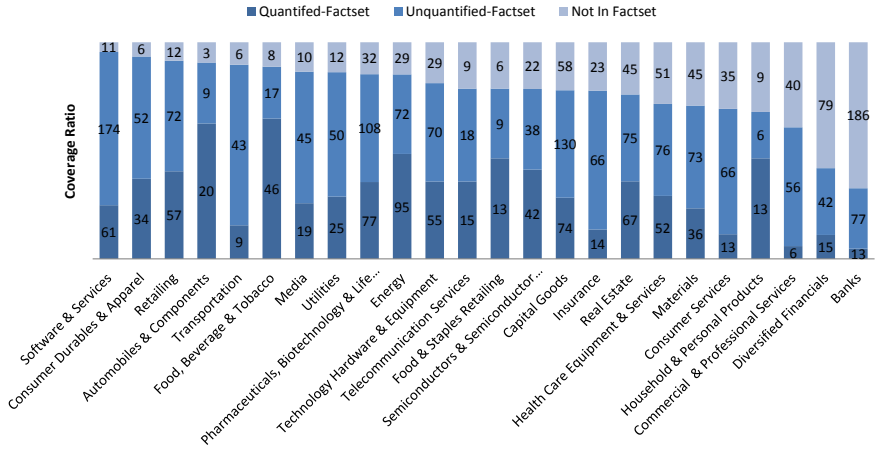
Figure 13: FactSet supply chain data sector coverage



Source: FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 13 shows that on the industry group level (see Figure 14), we still maintain a high coverage ratio of supply chain information for different companies. However, Banks still get the lowest coverage. It may be inappropriate to utilize supply chain networks for financial companies, as their core business is not centered around the production and distribution of physical products.

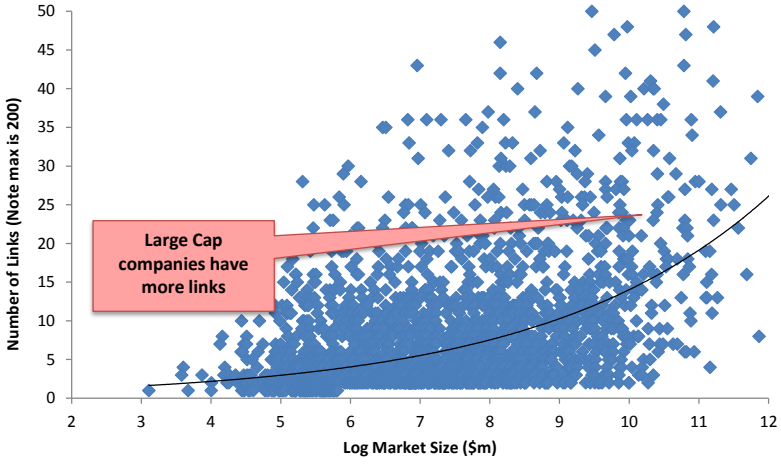
Figure 14: FactSet supply chain data industry group coverage



Source: FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

In addition to sectors, Figure 15 shows the scatter plot of the size of companies versus their degrees of connections. From the trend line, we can see that companies with more links are generally larger firms. On one hand, large companies typically generate revenue from a large customer base. Thus, they tend to have more customer relationships. On the other hand, large firms are more likely to span their business into multiple industries, diversified in terms of their product offerings. Thus, they tend to have more supplier relationships. Moreover, large and conglomerate firms are typically multinational companies as well, which also contributes to their large customer and supplier base due to sourcing convenience and transportation costs.

Figure 15: Scatter plots of size (log market cap) and the number of total supply chain links



Source: FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Supply chain vendors

There are a few data vendors offering supply chain information. In this section, we briefly discuss four popular ones.

FactSet

This is the data vendor we use for this study. The data has history from April 2003. There are about 1,000 quantified (or revenue-based) supply chain relationships per year, and about 25,000 total supply chain relationships collected every year.

Compustat

Compustat keeps a record of companies' 10-K fillings, so the supply chain relationships captured are all quantified – about 1,000 relationships every year. Compustat data starts from 1978. Compustat does not capture relationships from other sources aside from the 10-K filings.

Bloomberg

Bloomberg launched its supply chain product a few years ago on its terminal. The function <SPLC> brings the user to the Bloomberg supplier chain analytics, which shows a company's major suppliers, customers and competitors. Bloomberg currently does not allow access to the historical archive, so users can only access the most up-to-date cross-sectional supply chain network information. Bloomberg performs proprietary due diligence to estimate sales for over 10,000 cross-sectional supply chain links. Bloomberg offers 10,000 supply chain relationships with sales (actual or estimated) per year. Wu and Birge [2014] give a comprehensive description on Bloomberg <SPLC> data.

Thomson Reuters

Thomson Reuters has a supply chain data product in beta version. We have not studied that product yet, but we hope to investigate the dataset in the near future.

Voluntary Disclosure and Data Asymmetry

Another potential source of bias arises from voluntary disclosure, i.e., the subject companies can choose whichever supply chain partners they desire to disclose. For example, managers may want to disclose a reliable, large and well-known customer in order to send a positive signal to the capital market. Managers may also want to disclose if a government agency such as the Department of Defense is a customer, as government contracts maybe perceived as more reliable and lucrative. Ellis, et al, [2012] discusses in detail the implications of such voluntary disclosure on supply chain partners.

In general, it is very difficult to correct the bias caused by voluntary disclosure because the bias is actually unknown and difficult to systematically describe. One way to account for this is to try different weighting schemes for the unquantified supply chain links when we construct alpha factors, such as equal-weighted, market value-weighted, book value-weighted or sales-weighted schemes.

Another important factor to consider for the quantified supply chain data is the asymmetric direction of supply chain significance. Since the SEC requires all public companies to disclose their major customers, the customer companies are important to the suppliers, but not the other way around – the suppliers are not necessarily important to the customer companies. It is possible that a customer contributes to the major revenue of a supplier, while the same dollar amount of sales is negligible in terms

of the total purchase made by the customer company. Again using Apple as an example, some mobile game producers, such as Glu Mobile and Gameloft, report Apple as their major customers (Apple contributed to about 50% of Glu Mobile sales, and about 30% of Gameloft sales in 2014). However, they are among many content providers to Apple's App Store, and the expenses used to purchase from these two suppliers account for a small fraction of Apple's COGS.

Some recent research addresses the above-mentioned asymmetric disclosure. For example, Atalay, et al, [2011] builds a theoretical model using partial differential equation (PDE) to show that for the quantified relationships the customers take at least 10% of the supplier's sales – the supplier's COGS ratio of the customers in those relationships surprisingly have no bias in distribution, meaning the suppliers are evenly sampled from the customer company's perspective[5].

[5] Using their result, we can take the top quintiles using the sales on the supply chain divided by the customer's COGS or other normalizing variables to capture major suppliers in terms of customer's COGS, etc. in the quantified supply chain data. However, not only will our sample size of quantified relationships decrease significantly, but there is also noise due to the statistical property. As a result, for the quantified supply chain relationships, we expect the coverage to be much worse using the supplier momentum signal compared to the customer momentum strategy due to the shrinkage in the sample size. However, we expect the customer momentum to work better than the supplier momentum due to the smaller statistical noise on the customer side.

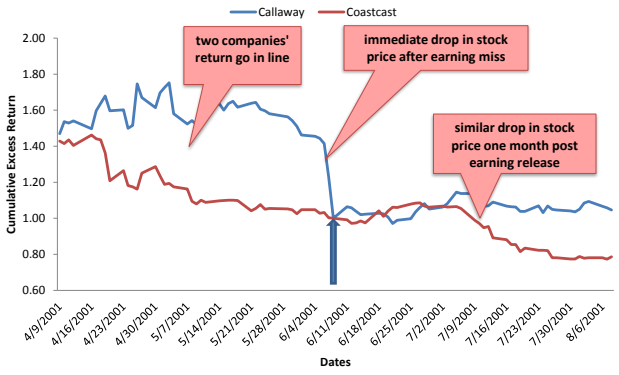
Disruptions to the Supply Chain

Examples of supply chain effects

Our hypothesis is that positive news or a negative shock in a company may radiate its effects through the supply chain linkages. For example, Calloway Golf Company (NYSE ticker: ELY) is a company that designs, manufactures and sells golf clubs and balls. On June 8, 2011, Calloway missed its second quarter earnings forecast by almost 50% ($0.36 reported EPS compared to $0.70 consensus expected EPS) – its stock price dropped 30% as a result. The multiplier effect began to permeate to Coastcast Corporation (a supplier to Calloway), which derives 50% of its sales from Calloway. As shown in Figure 16, stock price for Coastcast dropped approximately one month after Calloway's earnings miss.

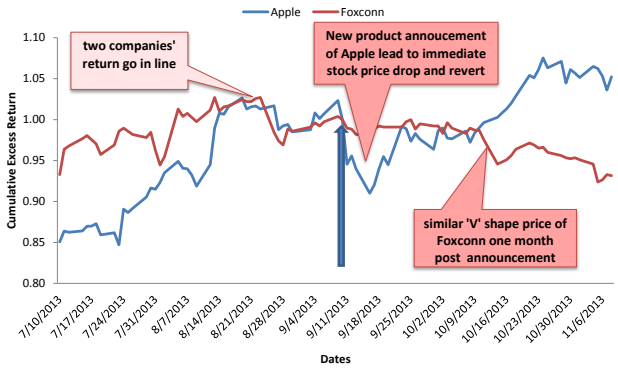
For larger companies like Apple Inc., such supply chain effects also exist with respect to its largest supplier, Foxconn. Apple released the iPhone5s and iPhone5c on September 10, 2013. The market interpreted Apple's earnings as disappointing and the stock tumbled in the ensuing days. Apple accounts for more than 40% of Foxconn's sales revenue, and as a result, Foxconn's share price also tumbled (see Figure 17).

Figure 16: Calloway and Coastcast



Source: Bloomberg Finance LP, FactSet, Deutsche Bank Quantitative Strategy

Figure 17: Apple and Foxconn



Source: Bloomberg Finance LP, FactSet, Deutsche Bank Quantitative Strategy

Event study methodology

To better understand the spillover effects along the supply chain, we conduct a number of event studies to analyze the propagation impact. We choose the list of corporate events that are intuitively related to both supplier and customer companies. For a more comprehensive study on corporate events, please refer to three of our previous research papers (see Luo, et al [2015a, 2015b, and 2015c]). We examine their effects on the companies themselves and their indirect effects on the upstream suppliers. Arguably, customer companies have more significant impact on their suppliers than the other way around.

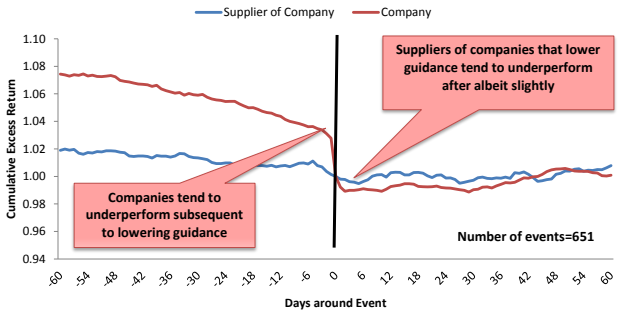
It is worth noting that we source corporate events from a few different databases. The guidance and dividend change events come from S&P Capital IQ's Key Development and Future Events (KDFE) database (see our previous research papers, Luo, et al [2015a, 2015b]). Stock buyback and M&A events are sourced from the Thomson Reuters Mergers and Acquisitions Database (see our previous research, Wang, et al [2015]). The earnings announcement events are sourced from News Quantified. We deliberately choose different event sources to ensure that we have the largest coverage and highest quality for each event type.

For event studies, we only select linkages that have the largest revenue contribution. Therefore, we ensure any disruption to customer has a reasonable impact on the upstream suppliers, and based on these logical linkages we begin our event analysis. We investigate stock price trend 60 days prior to and post the event occurrence date. We use the official announcement date or release date as day zero and analyze the cumulative effect.

Guidance change

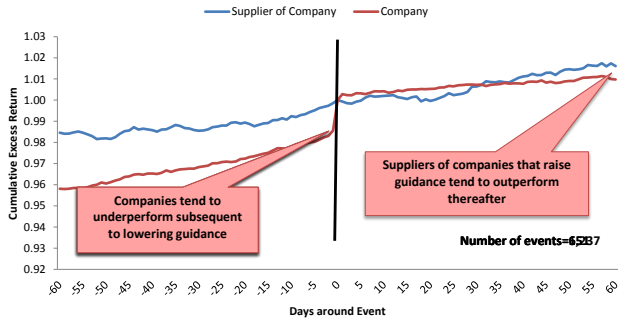
As discussed in Luo, et al [2015a], many companies voluntarily give guidance on their future earnings. Guidance can have significant influence over analysts' stock rating and price target. When a company raises (or lowers) its earnings guidance, we would expect the market reacts positively (negatively); therefore, the subject company's share price is more likely to increase (decrease). Moreover, the surprisingly positive (negative) news of the subject company may imply that its upstream suppliers also benefit (hinder) from such announcements. Figure 18 shows that when a company lowers its guidance, its share price drops along with its suppliers. Consequently, Figure 19 shows that after a company raises its guidance, its share price rises along with its suppliers.

Figure 18: Event Studies: Guidance Lowered



Source: Bloomberg Finance LP, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 19: Event Studies: Guidance Raised

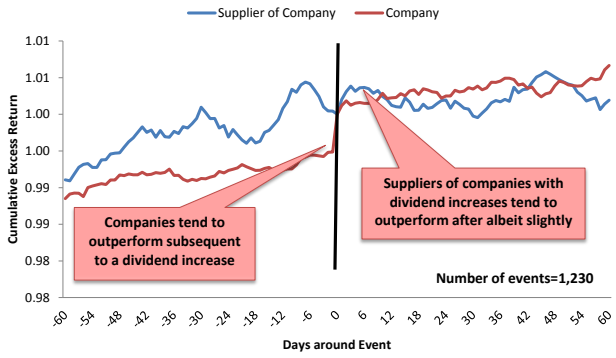


Source: Bloomberg Finance LP, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Dividend announcement

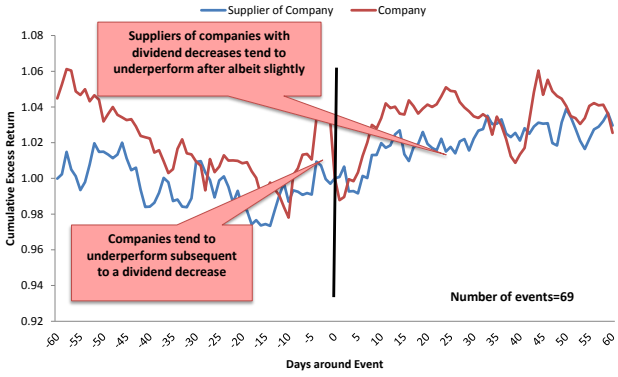
Based on the dividend signaling theory (see Luo, et al [2015b] and Wang, et al [2014a]), increasing dividends or initiation of new dividends send a positive signal to the market, while cutting dividends or suspending dividends are detrimental to share price. Interestingly, post dividend announcements, the upstream suppliers also embrace a similar (albeit more modestly) reaction on their share prices as the subject companies (see Figure 20 and Figure 21).

Figure 20: Event Studies: Dividend Increase



Source: Bloomberg Finance LP, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 21: Event Studies: Dividend Decrease



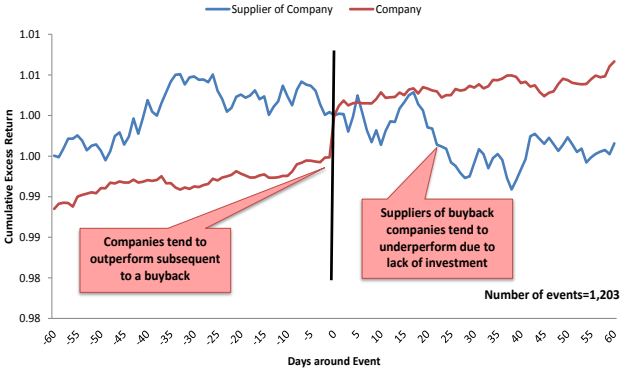
Source: Bloomberg Finance LP, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Stock Buyback and Merger and Acquisition

Similar to dividend announcements, as discussed in Luo, et al [2015b], share buybacks generally also send a positive signal to the market. As expected, the subject company's share price reacts favorably to buyback announcements (see Figure 22). Surprisingly, we see a price drop in the subjective company's supplier share price as a result of a buyback announcement. This is likely due to the fact that the company chose to repurchase stock as opposed to reinvesting the proceeds into the company, which can potentially benefit the supplier.

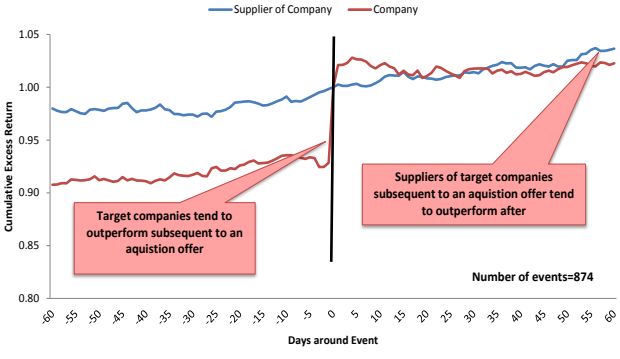
On the other hand, if a company becomes the target of an acquisition, its share price tends to jump immediately, as shown in Figure 23. Interestingly, the suppliers' stocks also react positively. Mergers are likely to create larger companies, which may purchase more products from suppliers. This may also due to potential vertical acquisition speculation, in that the acquirer firm may further purchase the supplier companies.

Figure 22: Event Studies: Stock Buyback



Source: Bloomberg Finance LP, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 23: Event Studies: M&A Target



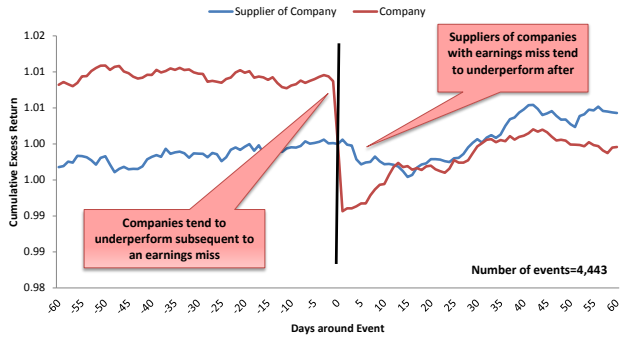
Source: Bloomberg Finance LP, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Earnings Announcement

As elaborated in Luo, et al [2014], an earnings announcement is one of most widely-watched corporate events. The market reacts positively to those companies that beat expectations, while penalizing those that miss their numbers. Companies along the same supply chain are unlikely to report on the same date. Therefore, those companies that report earnings first are likely to be perceived as barometers to other firms in the

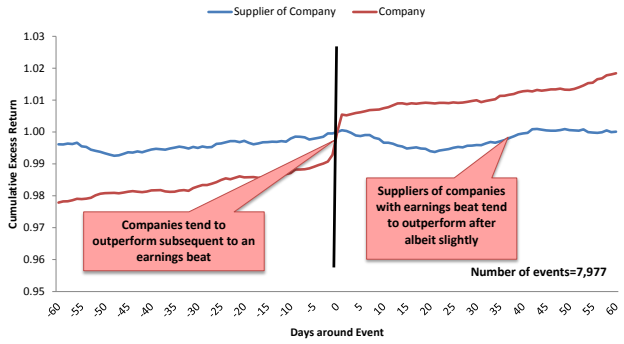
same supply chain network. As shown in Figure 24 and Figure 25, the earnings surprise effect does permeate to the supplier companies' share performance. When the subject company reports a positive (negative) earnings surprise, its suppliers' share prices also tend to increase (decrease).

Figure 24: Event Studies: Earnings Miss



Source: Bloomberg Finance LP, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 25: Event Studies: Earnings Beat



Source: Bloomberg Finance LP, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Supply Chain Alpha

Stock selection strategies and factors

The previous event study analysis hints that the supply chain network data may be useful in stock selection. In this section, we explore in detail whether supply chain network data contains any untapped alpha. In particular, we want to see whether previous published research on predicting returns along firm interconnections (Cohen and Frazzini [2008], Menzly and Ozbas [2010], Wu and Birge [2014] and our own research, Cahan, et al [2013]) have washed away supply chain alpha.[6]

To accomplish this, we form a series stock-selection factors or signals based on the supply chain network data. The sheer vast array and complexity of the supply chain dataset requires some thought and thoroughness when constructing factors. There are numerous potential strategies that we can create based on this dataset. We bucket these strategies into the following three groups:

- Return momentum (see Figure 26): The rationale underlying this factor category is that the performance of a company's customers may permeate or be correlated to the company's own performance with a lag. To test this premise, we create equity strategies based on information from the company's customers. For example, we test whether the one, six or twelve-month return of a company's largest customer is a strong predictor of the company's own stock return. We also test whether a weighted combination of a company's customers can predict the company's stock price. We weight each customer company's return momentum by several metrics including annual sales, annual cost of goods sold, market cap and book value. Additionally, we repeat the same analysis but utilize a company's supplier information.

Figure 26: Return momentum factors

	Return formation horizon		
Weighting scheme	One-month	Six-month	12-month
Largest customer	x	x	x
All customers - equally weighted	x	x	x
All customers - sales weighted	x	x	x
All customers - COGS weighted	x	x	x
All customers - book value weighted	x	x	x
All customers - market cap value weighted	x	x	x
Largest supplier	x	x	x
All suppliers - equally weighted	x	x	x
All suppliers - sales weighted	x	x	x
All suppliers - COGS weighted	x	x	x
All suppliers - book value weighted	x	x	x
All suppliers - market cap value weighted	x	x	x

Source: FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

[6] In the past we have worked on alpha signals across economically linked firms (Cahan et al. [2013]) and trade-linked countries (Mesomeris et al. [2010], Rizova [2010]). The methodology in this research is materially different from all previously published research.

- Fundamental flow through (see Figure 27): Can the fundamentals of a company's suppliers impact the company's own operations, and therefore, stock return? This is the very notion underlying this factor category. We test various fundamental factors of the company's suppliers to see if these metrics are correlated to future stock returns of a company. We analyze a company's suppliers ROE (return on equity), ROA (return on assets), earnings yield and gross profit margin to test if these metrics can predict the company's share price performance. We again weight the supplier fundamentals by several metrics including annual sales, annual cost of goods sold, market cap and book value. We repeat the same analysis but utilize a company's customer information.

Figure 27: Fundamental flow through factors

Weighting scheme	Suppliers	Customers
Equally weighted	x	x
Weighted by COGS	x	x
Weighted by Book value	x	x
Weighted by market cap	x	x
Weighted by ROE	x	x
Weighted by ROA	x	x
Weighted by earnings yield	x	x
Weighted by gross margin	x	x

Source: FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

- Link interactions (see Figure 28) Can the number of link chains add any alpha? How does the multiplicity of links affect a company's risk and returns? Here we test whether the total number of links to a company is a strong stock selection factor. Additionally, we test whether the number of inward links (i.e. customers), number of outward links (suppliers), as well as the difference between the number of inward and outward links are strong stock selection signals. On one hand, more supplier links may mean more redundancy in terms of input sources, making a company's operations more expensive but more robust in terms of upstream negative shocks. This would reduce the company's risks and lowers its returns. On the other hand, more customer links may entail a diversified customer base, thereby reducing the company's risks and lowering its returns.

Figure 28: Link interaction factors

Number of total degrees
Number of inward degrees
Number of outward degrees
Difference between inward and outward degrees
Number of total degrees / Sales
Number of total degrees / COGS
Number of total degrees / Market Cap
Number of total degrees / Book Value
Number of total degrees (residual by Market Cap)

Source: Deutsche Bank

- Neutralization of biases: Understandably, many of the factors discussed above can take on sector as well as size biases. For example, companies with multiple links, are on average larger companies. As such, we are careful to neutralize the factors for the sector and size effects.

To show the performance of the above mentioned factors, we form equally-weighted long/short portfolios based on these factors. In total, we backtest approximately 110 alpha factors including all the size and sector-adjusted variants. We backtest these

portfolios over a 13-year period using monthly rebalancing. All the factors are backtested over the same period so that the portfolios are comparable across all strategies.

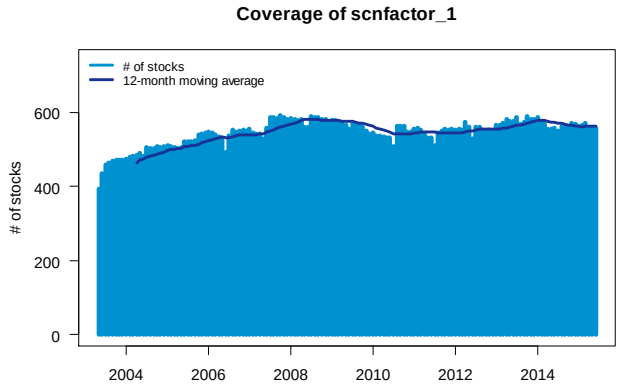
Before comparing the performance of all the above factors, we examine the backtesting results of a select few supply chain factors to better understand the return structure and overall results.

Individual strategy results

Return Momentum Factors

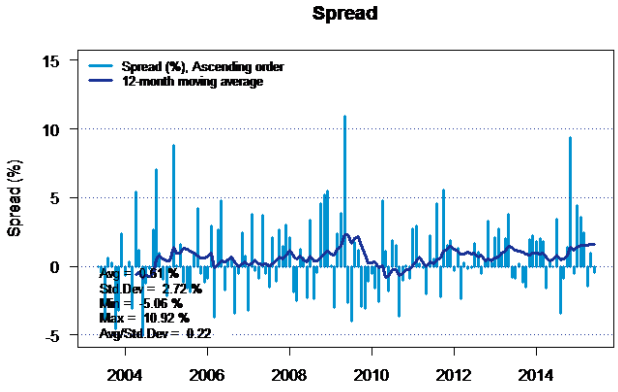
We start by analyzing the performance of one of the simplest factors – the one-month return of a company's largest customer based on revenue (see Cohen and Frazzini [2008]). The factor coverage is somewhat limited but reasonable (see Figure 29), as it is based on which companies disclose their customer revenue.[7] Forming a long/short portfolio based on the return of a company's largest customer yields some promising results. Figure 30 shows the time series performance of the long/short portfolio. The average performance is consistently positive and the average annualized alpha is an impressive 7.8%.

Figure 29: Coverage of one-month return of largest customer



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 30: Long/short performance of one-month return of largest customer

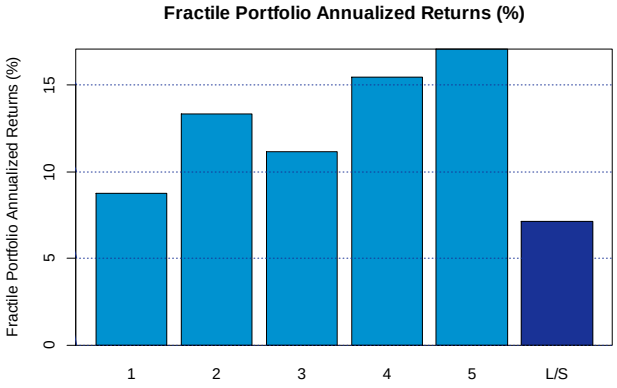


Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 31 shows the annual return of each quintile portfolio. A strategy that takes a long position in companies whose largest customer has a strong one-month return and shorts companies whose largest customer has a weak or negative one-month return is a viable strategy. This is interesting because, typically, betting on companies with a large one-month return is a reversal or mean reverting factor. However, incorporating the customer data shows that such a strategy is more based on momentum and trending. Figure 32 shows the Sharpe ratio of each quintile portfolio. We also find that the payoff pattern is non-linear. However, the Sharpe ratio is an impressive 0.7x.

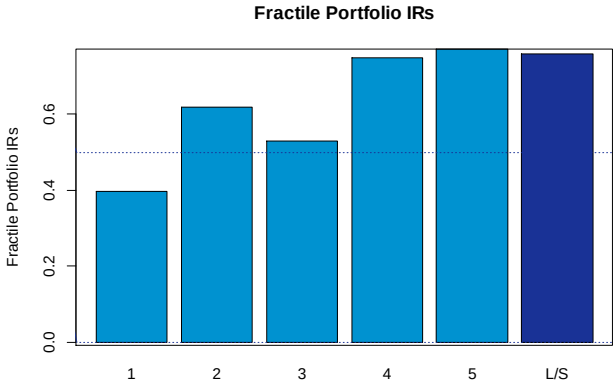
[7] Additionally, it also depends on which customers disclose their suppliers sales and cost of goods sold.

Figure 31: Quintile return – largest customer one-month return



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

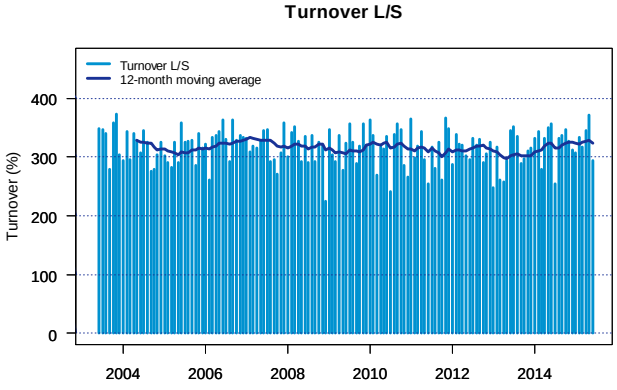
Figure 32: Sharpe – largest customer one-month return



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

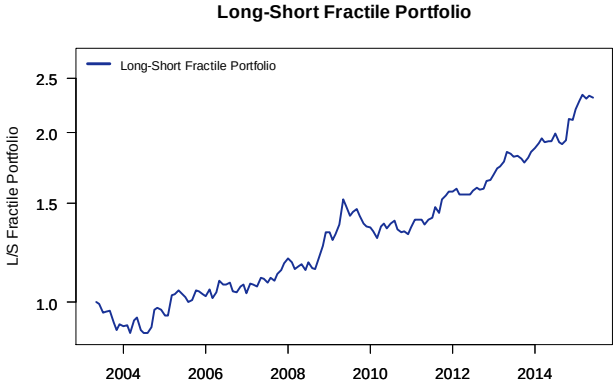
Understandably, the turnover is fairly high since the strategy is based on the short-term (i.e., one-month) return of a company's largest customer. Turnover can be subdued as we utilize a longer return period. Later in this section, we analyze the six and 12-month return formation windows. These factors have considerably lower turnover. Figure 34 shows the long/short portfolio cumulative performance, which is fairly consistent.

Figure 33: Turnover – largest customer one-month return



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

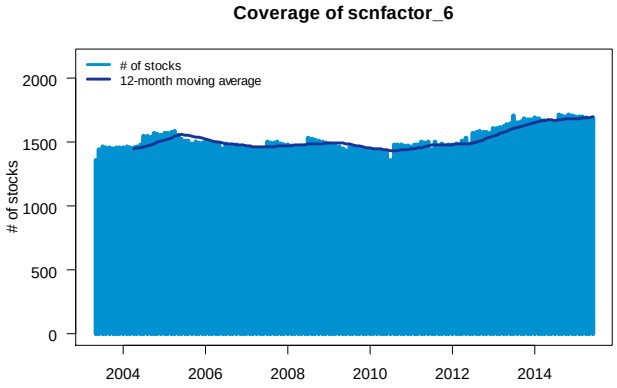
Figure 34: Wealth – largest customer one-month return



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

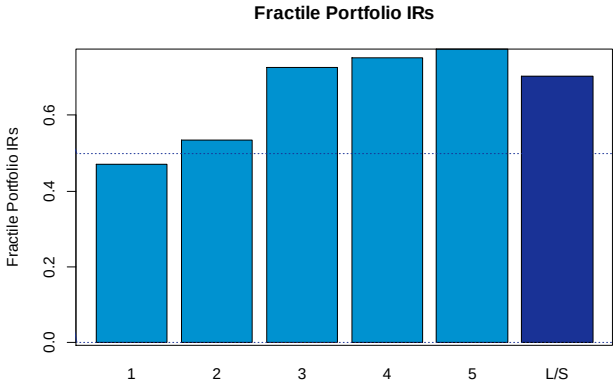
Another interesting return momentum factor is the 12-month return of all the company's customers. Again, the rationale underlying this factor is that a company's customer performance may be indicative of the company's own performance. Since a company will have several customers, for this particular factor we choose to weight the 12-month return by each customer's revenue. The argument is that larger customers may better serve as indicators of the subjective company's performance. Since we do not require the actual sales data to each customer, the data coverage of this factor is about three times larger than the one-month customer momentum factor above (see Figure 35). We also backtest various other weighting schemes such as equally weighted and value weighted. The Sharpe ratio is fairly impressive at 0.65x (see Figure 36), with a linear payoff.

Figure 35: Coverage of 12-month return of customer, revenue weighted



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

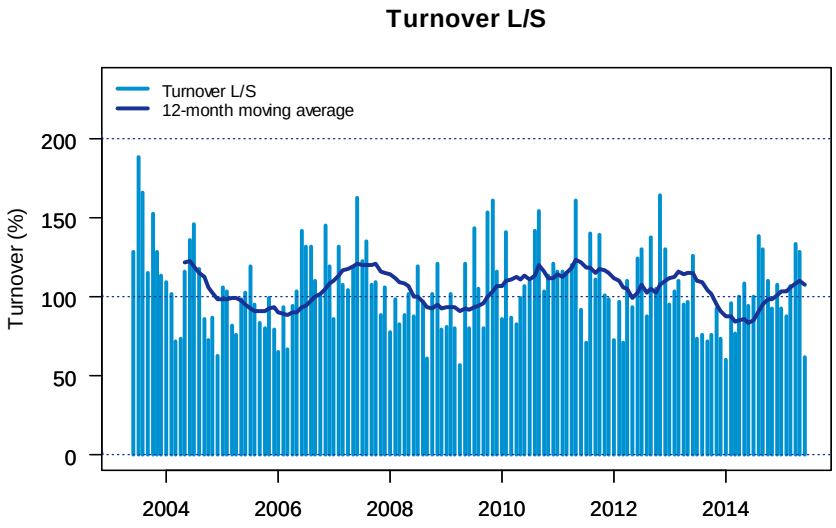
Figure 36: Sharpe performance of 12-month return of customer, revenue weighted



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Since this strategy is based on a 12-month return window, its turnover is considerably lower than that of the one-month customer momentum factor (see Figure 37).

Figure 37: Turnover, 12-month return of customer, revenue weighted



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Link Interaction Factors:

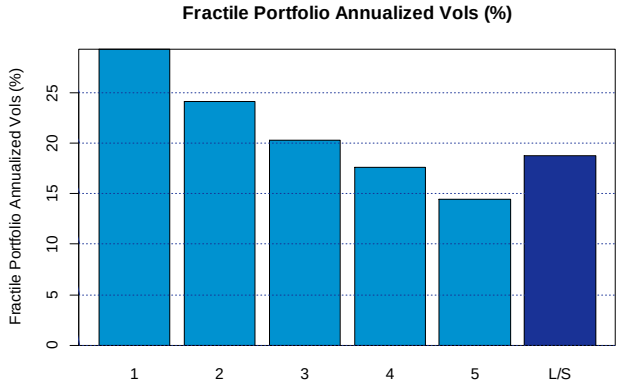
We also take a closer look at the link-based factors. Recall that link-based factors are essentially the number of inward and outward link attachments based on the supply chain. One interesting link-based factor is the number of total links. This is the summation of the number of inward links (suppliers) plus the number of outward links (customers). We adjust this signal for size since companies with more number of links are likely to be larger cap companies.

Figure 38 shows the annualized volatility of each quintile portfolio. Interestingly, our results show that companies with more linked customers and suppliers are less volatile. This suggests that companies with more dependencies are, on average, lower risk companies, which agrees with our previous intuition on supplier redundancy and customer diversification. These companies may have more embedded redundancy in terms of suppliers and even customers, or they may have some backward or forward supply side integration corporate structure.

Additionally, more customer links may mean a more diversified customer base, so a customer shock or disruption would not impact the company as significantly. More supplier links may also be indicative of more redundancy in supplier base to increase reliability, such as a company sourcing contracts from several different suppliers that are diversified by region. This is generally referred to as operational hedging, a common practice typically used by high-margin manufacturing companies.

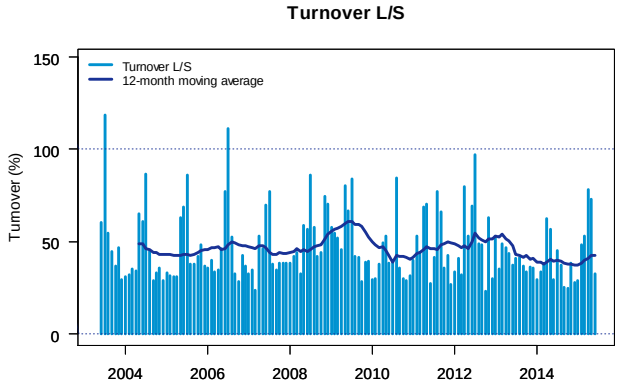
The turnover of such a portfolio strategy is fairly low, indicating that the supply chain network is fairly persistent and stable (see Figure 39).

Figure 38: Performance of quintile portfolios, total number of degrees, size adjusted



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 39: Turnover of long/short portfolio, total number of degrees, size adjusted



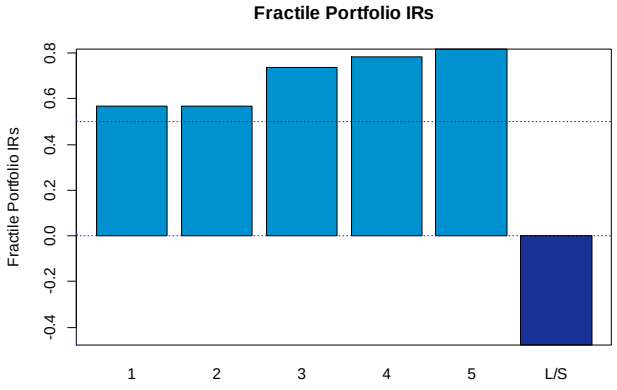
Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

It is also interesting to note that since companies with more dependencies have lower risk on average; these companies also have lower returns (see Figure 38). As such, there is an embedded risk premium.

As seen in Figure 40, companies with a higher number of supply chain links have lower Information Ratios. Conversely, companies with a lower number of links command a risk-premium. This is due to the fact that they are not logistically hedged. This exposes the investor not only to shocks to the company itself, but also to those of its immediate suppliers and customers.

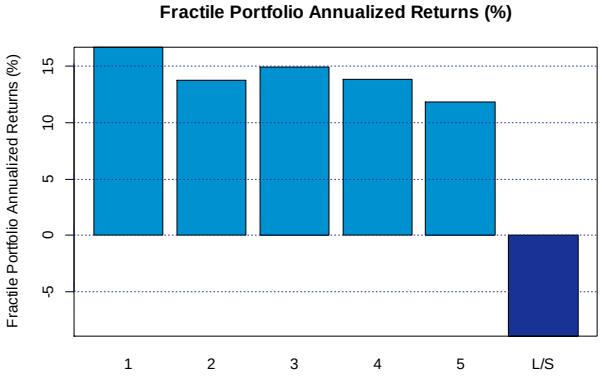
We note that – as a local metric – the number of links does not tell us whether a firm is systemically important to the supply network. Firms can have many links to companies that are, themselves, not very important, or they can be linked to other important companies. In the latter case, the company is deemed to be of systemic importance, thus, commanding a risk premium for significant exposure to systemic risks such as the 2008 crisis. We discuss this topic in the last section of our paper.

Figure 40: Quintile Information Ratio – total number of degrees, size adjusted



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 41: Quintile return – total number of degrees, size adjusted



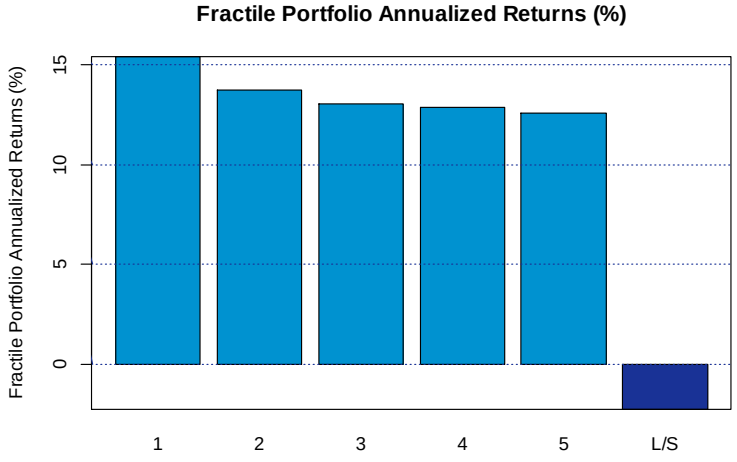
Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Fundamental Flow Factors:

Next, we analyze fundamentally-driven factors derived from the supply chain. Can the fundamental financials and operations of customer or supplier firms be predictive of a company's own performance? Here, we observe whether the average gross profit margin of a company's customers is indicative of the company's stock return. Our signal is the equally-weighted gross profit margin of a company's customers.

As shown in Figure 42, interestingly, companies whose customers have higher profit margins underperform those firms with less profitable customers. This is fairly intuitive because if a company's customers are fairly profitable with high gross margins, this would entail that its customers have superior pricing power, as opposed to the subject company (i.e., the supplier). The results are in line with the classic supply chain business theory.

Figure 42 Long/short portfolio quintile return, customer gross profit margin, equally weighted



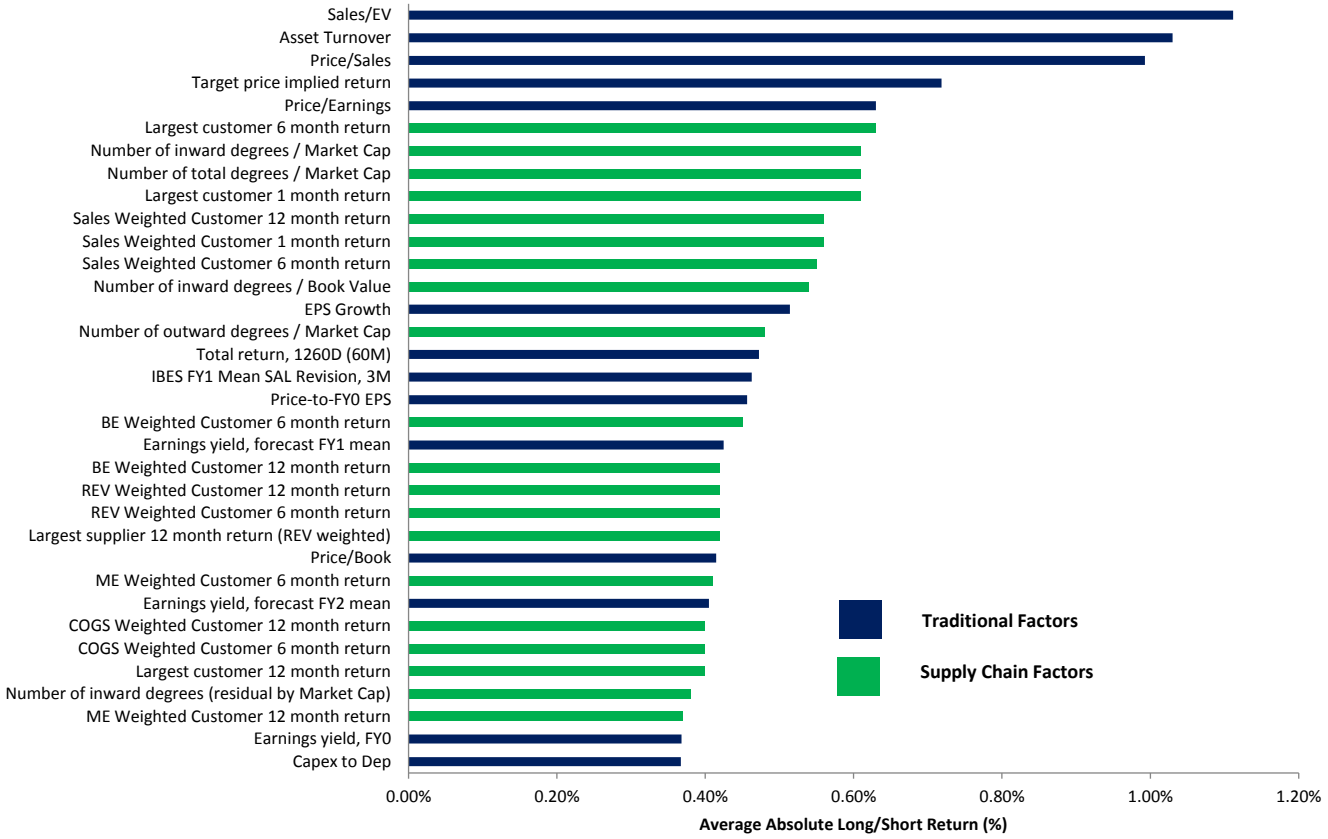
Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Now that we have briefly glimpsed the performance results for a few supply chain factors, next we compare the performance of all the supply chain factors to traditional quantitative factors.

Overall backtesting results

Figure 43 shows the monthly return of the supply chain factors alongside some of the best traditional quant factors. The results are promising. The supply chain based factors stack up fairly well compared to traditional quant factors backtested over the same period. The degree and return-based supply chain factors show the most promising results.

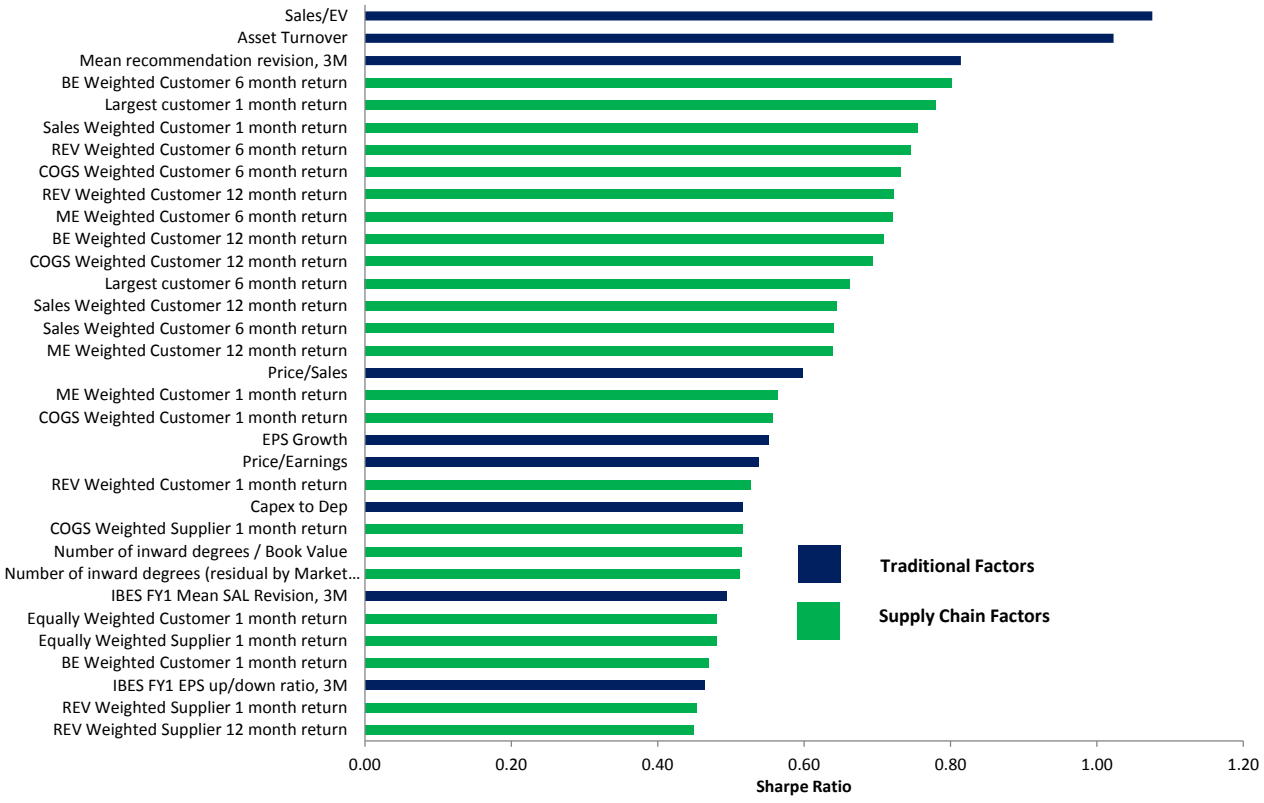
Figure 43: Supply chain network factors backtested, long/short absolute portfolio returns



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 32 shows the Sharpe ratios of the supply chain factors alongside the traditional quant factors. The results are again promising. Customer return factors across different horizons seem to dominate, which further confirms our hypothesis – customer companies are more likely to lead supplier firms.

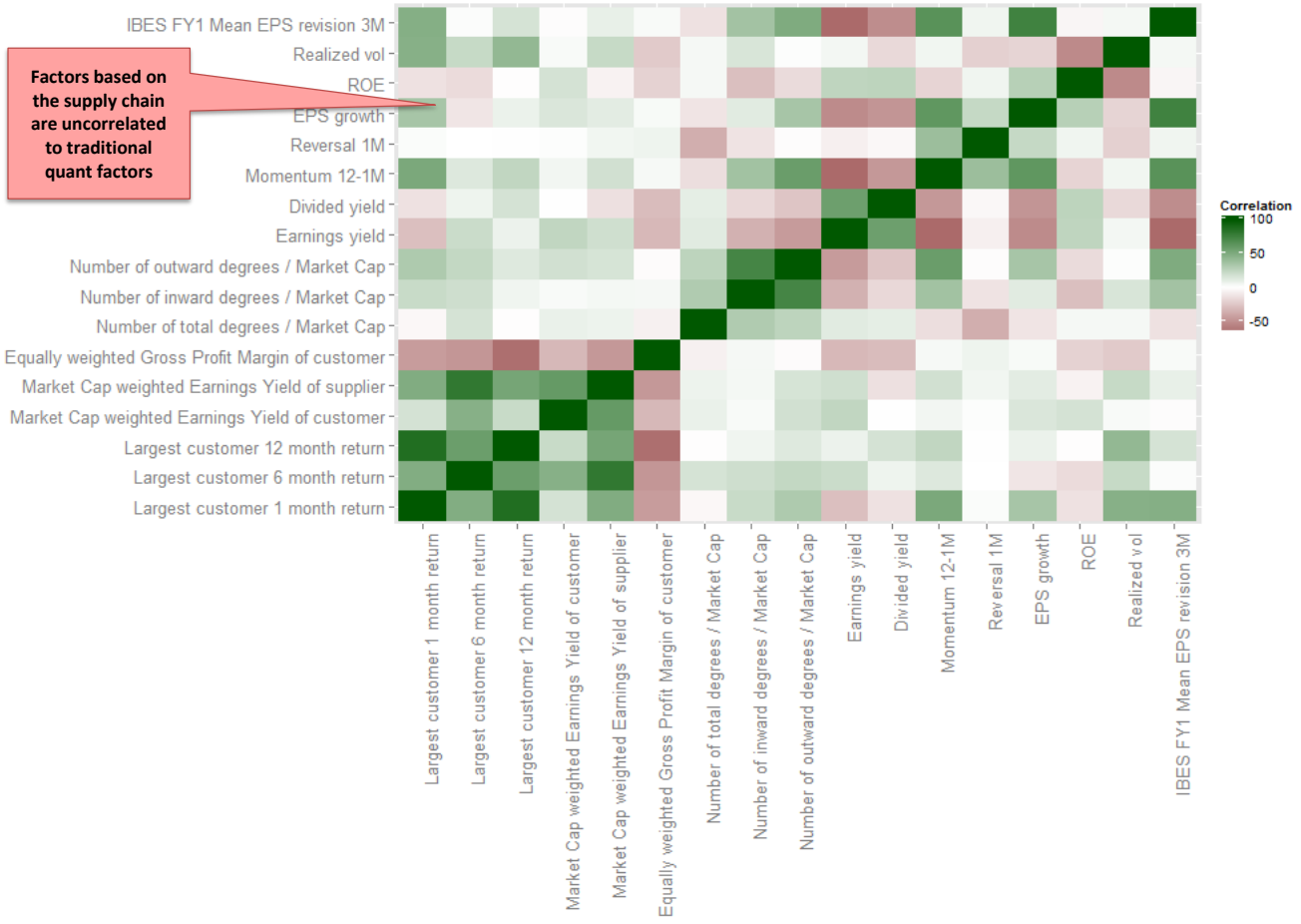
Figure 44: Supply chain network factors backtested, Sharpe ratio



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 45 shows the performance correlation of supply chain factors with traditional factors. It is worth noting that factors based on supply chain network information are somewhat uncorrelated with the traditional factors. Some supply chain factors are also minimally correlated within themselves, such as different degree factors shown in the figure.

Figure 45: Supply chain network correlation matrix



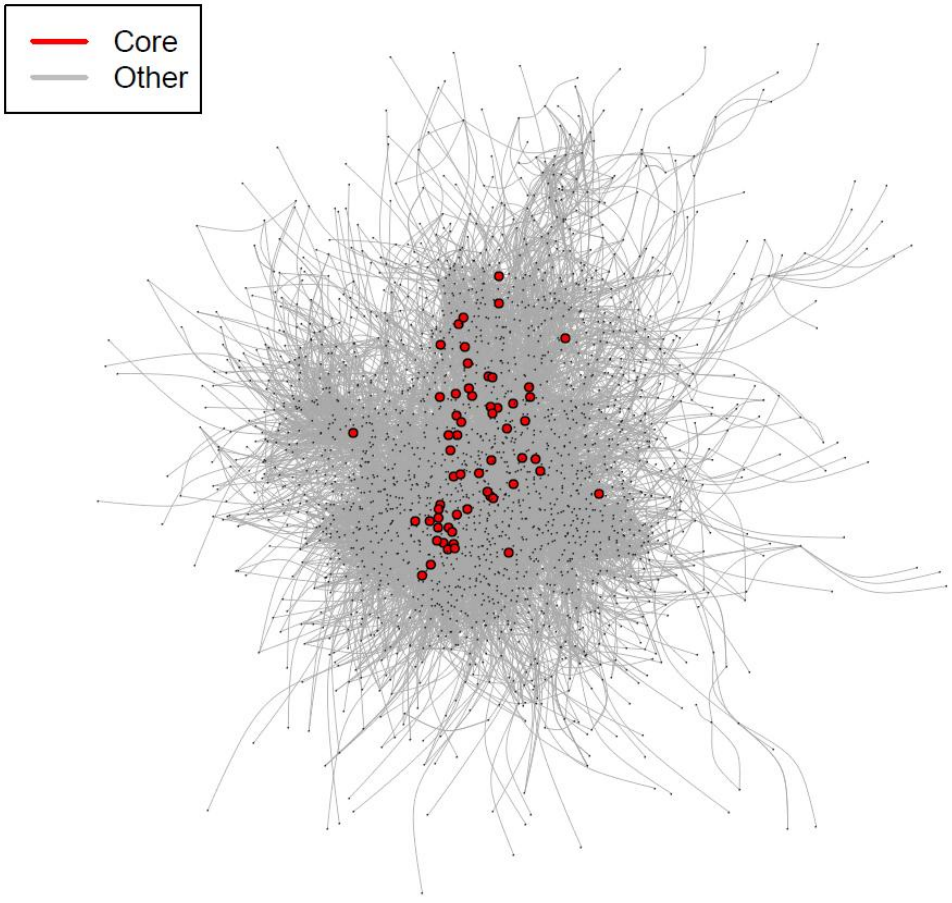
Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Six Degrees of Separation

You have probably heard of the so-called "six degrees of separation", in that everyone and everything is only a few steps (i.e., six or fewer) away, by way of introduction, from any other person in the world. Frigyes Karinthy[8] initially pointed it out in 1929 and the concept was later made popular by John Guare in a 1990 play.

Not surprisingly, we see the same pattern using our customer-supplier chain data. We call the 'core' companies that are only six degrees (steps) or fewer away from other companies. Please note that they are not necessarily the ones with the largest numbers of links (Figure 46).

Figure 46: Example of core companies



Source: FactSet, Russell, Deutsche Bank Quantitative Strategy

All the previous sections looked at local properties of the supply chain – the number of suppliers and customers that a company has, and the immediate spillover effect of one company onto its linked companies. This section uses algorithms from social networks and web search to unlock novel information on the position of a company within the supply chain as a whole. Interested readers please refer to Borgatti [2005] as well as

[8] See "Everything is Different", Frigyes Karinthy, 1929, https://djjr-courses.wdfiles.com/local--files/soc180%3Akarinthy-chain-links/Karinthy-Chain-Links_1929.pdf

Bonacich and Lloyd [2001] for comprehensive treatments on different centrality measures in network graphs.

These algorithms allow investors to systematically answer the following questions across the full breadth of the supply chain network:

1. Which companies are the end-suppliers of the supply network?
2. Which companies are the end-customers of the graph?
3. Which companies represent significant 'chokepoints' of the economy?
4. Which companies – regardless of their supplier or customer status – lie in the center of the supply chain?
5. Which companies lie on the periphery of the supply graph?

In addition to being important in their own right, the answers to these supply-chain questions also lead to intuitive alpha on certain key sectors of the economy.

Google PageRank

Moving upstream and downstream along the supply chain

We will not bore the readers with the detailed description or history of graph theory applied to social or website networks. However, in order to explain how the approach differs from the previous sections, let us start from Internet searches.

The Internet is a vast network of websites pointing at each other via hyperlinks. While a human can, with reasonable ease, determine the importance of a website searching around with a few clicks, the sheer size of the web all but imposes an algorithmic approach. The groundbreaking algorithm offered by Larry Page, named PageRank[9], rests on two crucial insights and uses a clever model to allow a computer to simulate human behavior and systematically rank the importance of the countless websites on the Internet.

1. The first idea is that hyperlinks are directed. The direction of these links is very important: not all hyperlinks from site A to site B are returned, especially if site B is much more popular than site A (see Figure 47). Hence, incoming links are much more important[10] than outgoing links in ranking a website's importance. If a page has more incoming links, it is probably more important because other pages link to it.

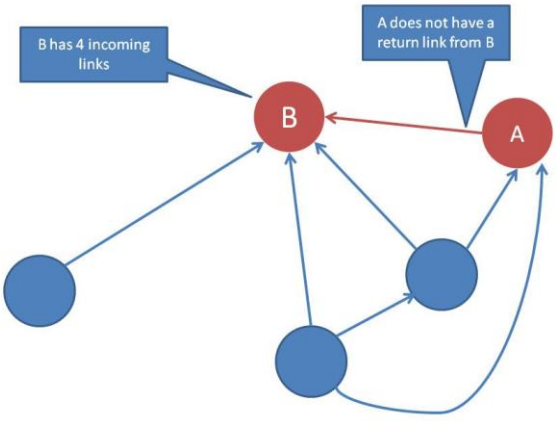
2. Just looking at the number of incoming links for a website – or any other local measure of a website's importance – can be affected by the system. Indeed, until recently, it was very common to create fake websites with the sole purpose of pointing hyperlinks at some target website to artificially boost its importance. However, few users ever visited these fake websites, which means the importance of these hyperlinks should be excluded.

[9] For detailed PageRank algorithm description, please refer to Lawrence Page, Sergey Brin, Rajeev Motwani, Terry Winograd. "*The PageRank Citation Ranking: Bringing Order to the Web*". http://ilpubs.stanford.edu:8090/422/1/1999-66.pdf

[10] This does remind us that the link from customers tends to be more important than the one from suppliers.

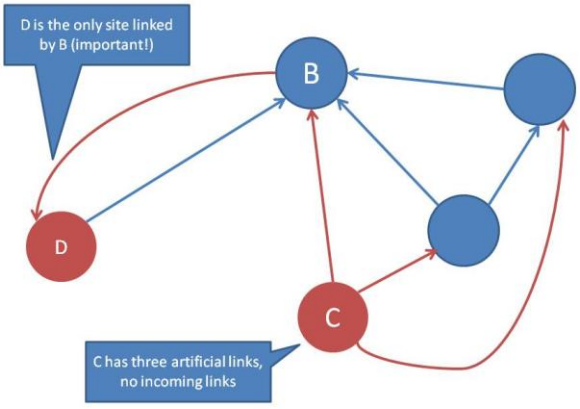
3. Websites inherit the importance of websites that link to them. Therefore, an incoming link from an important website will increase its own importance. However, a website being linked from an unimportant website will only marginally increase the former's importance. Important websites link to important websites, while links from unimportant websites are neglected (see Figure 48). Furthermore, the inherited importance of a website is diluted by the number of outgoing links of that website. Note that the direction of the links is crucial to the algorithm.

Figure 47: Example of schema-directed links



Source: Deutsche Bank Quantitative Strategy

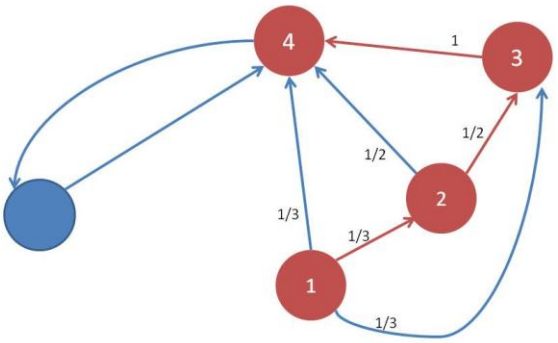
Figure 48: Example of schema search farm



Source: Deutsche Bank Quantitative Strategy

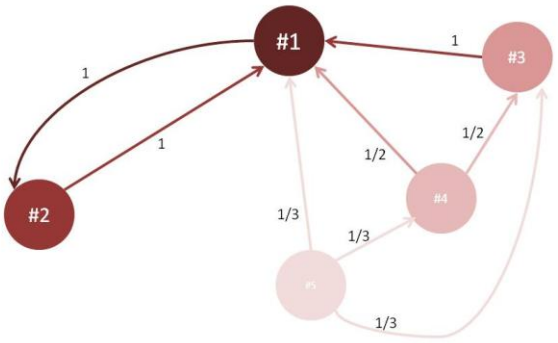
The original solution to this problem is called page rank. Without getting into detailed formula, let us present the model of human behavior that the algorithm uses. A user visits a website. Then, he/she randomly visits one of the links on this website, leading him/her to a new website to browse. This leads to new links to consider and randomly choose from. Eventually, browsing from page to page following random links, the user finds the website that he/she is looking for (see Figure 49). Upon reaching the final website, the user has crossed various websites. The page rank algorithm measures the frequency of visits of all the websites that the user has crossed to reach what he/she was looking for. The algorithm gives a higher importance to websites that have been crossed more frequently (in a simulation manner, leading to a heat map such as in Figure 50). When simulating the above random walk, the average length of the crossed links is approximately seven websites.

Figure 49: Example of a simulated search path



Source: Deutsche Bank Quantitative Strategy

Figure 50: Heat map after many simulations

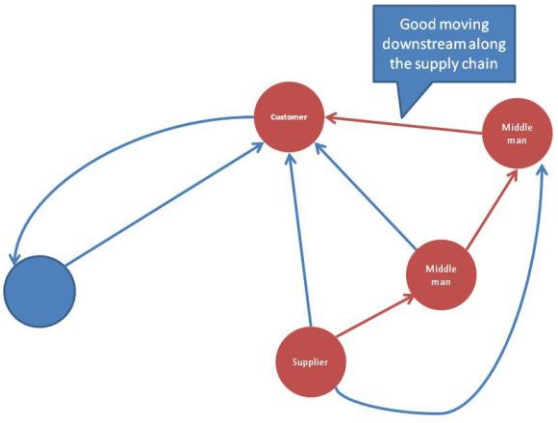


Source: Deutsche Bank Quantitative Strategy

Let us consider the supply network analog of this model. In this case, we follow goods along the supply chain. Our links are directed. Let us consider those that point from a supplier to a customer. If we follow the page rank model on these links (think of the user searching for a website now being replaced by goods 'searching' for a customer, Figure 51), the score of a particular company represents how often the goods cross through a particular company. In other words, companies with an important page rank score are critical in the customer fulfillment process, as they are most frequently crossed.

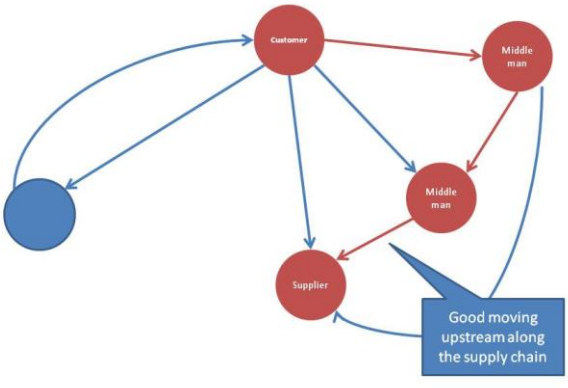
Now switch the direction of all the links. They now point from customers to suppliers: the goods move upstream instead of downstream (see Figure 52). Therefore, our page rank algorithm applied to the supply chain identifies the main suppliers of the economy (i.e. those that are most frequently crossed).

Figure 51: Example of a downstream path



Source: Deutsche Bank Quantitative Strategy

Figure 52: Example of a upstream path



Source: Deutsche Bank Quantitative Strategy

This provides us with a systematic, quantified screen for the major upstream and downstream players of the supply chain. Similar to the website example, while a user may do a better job for a single company, the algorithmic approach is a must when comparing thousands of companies and tens of thousands of links.

Our social networks factors

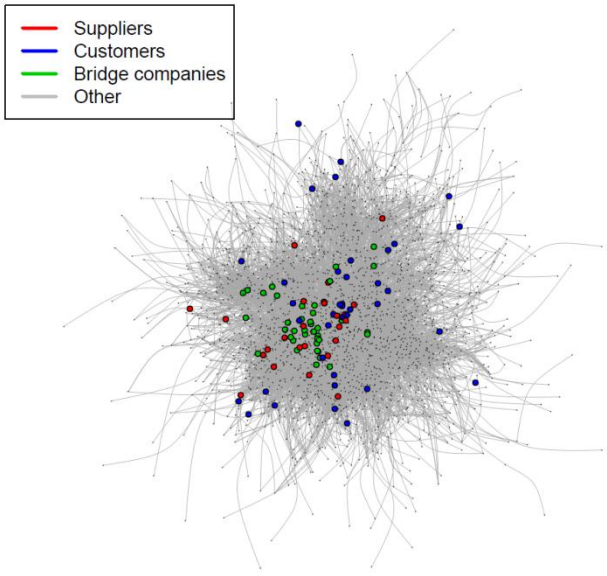
Let us now introduce our graph-centric factors based on these algorithms:

- Supplier and Customer Importance: Based on the above page rank algorithm, we score companies based on how far upstream or downstream they are placed within the full supply chain graph. This represents the importance of a company given a directional path (upstream or downstream).
- Bridge/chokepoints: Similarly, we can identify 'bridge' or 'chokepoint' companies. These companies play a central role in the supply chain, i.e., if they were to be removed from the network, the average length between suppliers and customers would be greatly increased. This makes them of systemic importance. If one of these nodes is removed from the supply chain, then the fulfillment process would be significantly lengthened. Specifically, a chokepoint is a metric that states the number of shortest undirected paths crossing it.
- Core and Periphery: We also identify the companies that are at the core of the graph. They can reach every other company on the graph within the minimum number of links. The opposite of the core is the periphery – the companies furthest away from the core.

In a nutshell, we can identify which companies really matter in the supply chain, and classify them accordingly. However, this would not be possible without analyzing the supply chain as a whole!

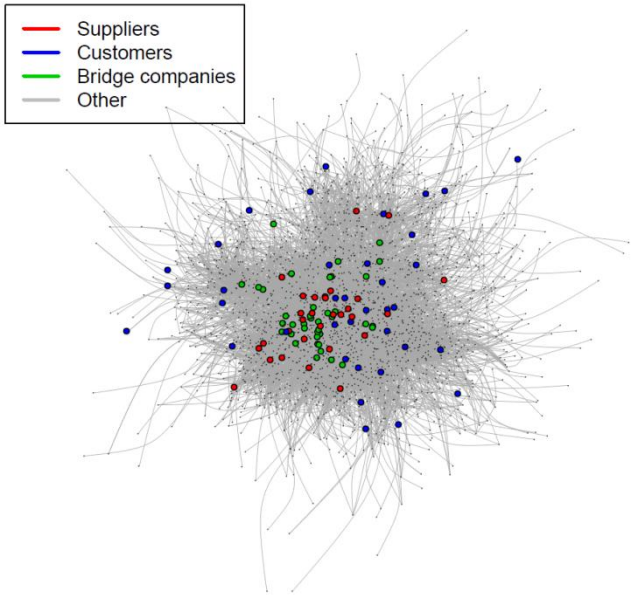
We illustrate the evolution of the supply chain over time (see Figure 53, Figure 54 and Figure 55), taking care of always positioning each company on the same spot at each time step. We note that most suppliers lie close to the core of the supply chain and are relatively stable. Customers, on the other hand, can be placed either inside the core or at the periphery. Chokepoint companies tend to be close to the core, and very much clustered together (see Figure 57 and Figure 58).

Figure 53: Top suppliers, customers and bridge/chokepoints as of December 2006



Source: FactSet, Russell, Deutsche Bank Quantitative Strategy

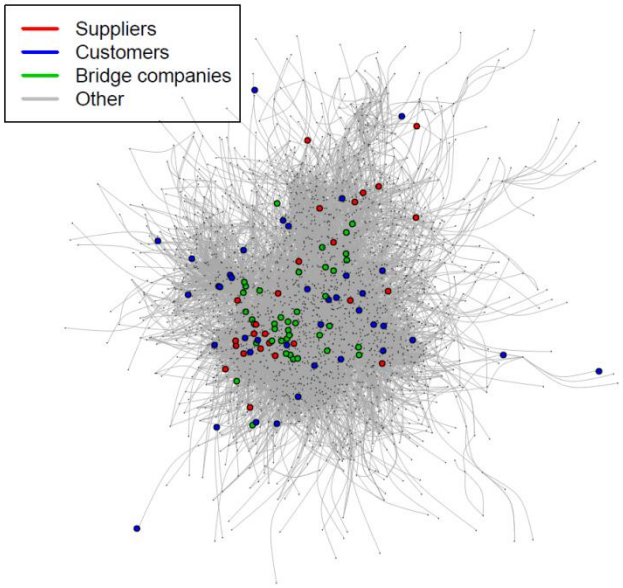
Figure 54: Top suppliers, customers and bridge/chokepoints as of May 2007



Source: FactSet, Russell, Deutsche Bank Quantitative Strategy

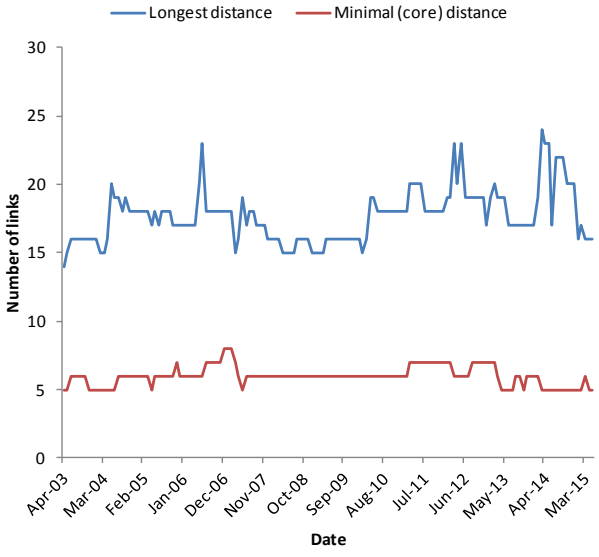
As a comparison, a network experiment on the billion users of social media website Facebook has led to an estimated core distance of six and a maximum distance of 12, in line with the popularized notion of 'six degrees of separation' between all humans of Earth. We note that we do not have the complete supply chain network data. Therefore, the actual distance between the core and peripheral (see Figure 56), as well as the largest distance between any two companies may be shorter in actual supply chain networks.

Figure 55: Top suppliers, customers and chokepoints in December 2011



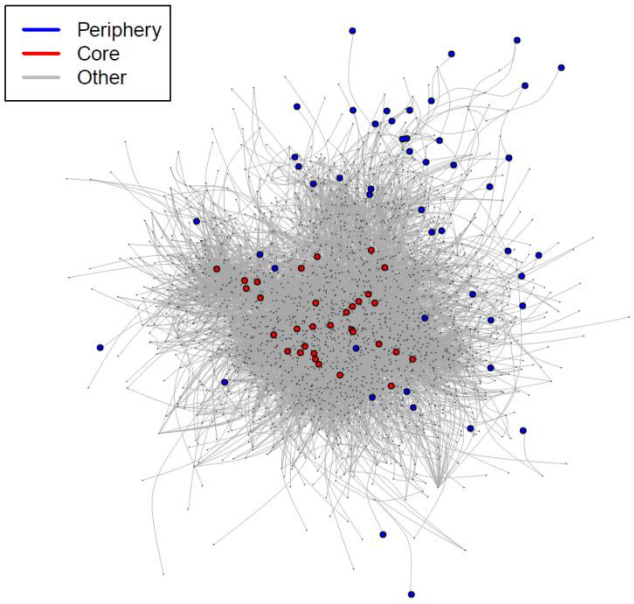
Source: FactSet, Russell, Deutsche Bank Quantitative Strategy

Figure 56: Longest (directed) distance between two companies; minimum (undirected) distance between core and periphery



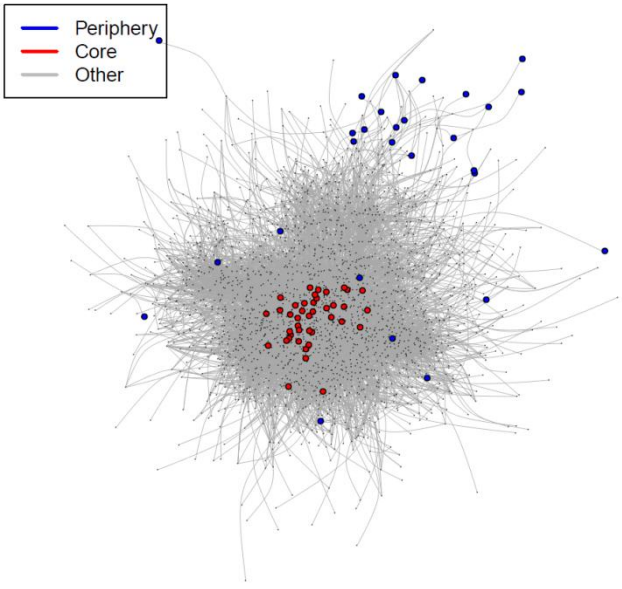
Source: FactSet, Russell, Deutsche Bank Quantitative Strategy

Figure 57: Core and periphery as of July 2007



Source: FactSet, Russell, Deutsche Bank Quantitative Strategy

Figure 58: Core and periphery as of June 2009



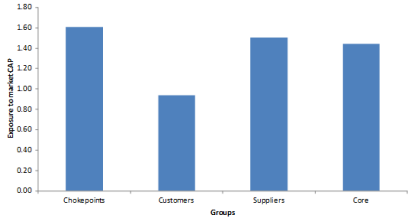
Source: FactSet, Russell, Deutsche Bank Quantitative Strategy

Top suppliers and customers are large-cap companies

Coverage and exposures of our network factors

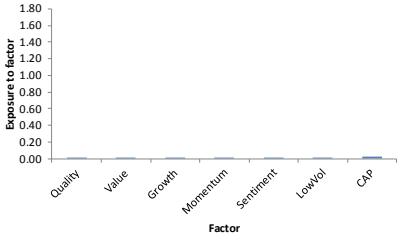
It hardly comes as a surprise that companies that play some significant role in the supply chain are bound to have a large-cap tilt (see Figure 59). It is important to note that our data set as a whole has almost no exposure to all common factors, including size, as shown in Figure 60. However, companies that our network algorithms classify as important suppliers, customers and bridge or core companies invariably have a large-cap bias. This should be accounted for when building our strategies.

Figure 59: Market cap exposure of each group of companies; z-score



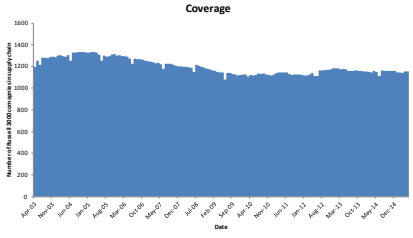
Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 60: Factor exposure of the full supply network; z-score – no inherent bias in dataset



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 61: Coverage within our Russell 3000 universe



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Go long chokepoints/bridge companies

The key findings of this section are that chokepoints outperform the rest of the supply network, but are structurally exposed to systemic risk. This implies that there is an embedded risk premium for chokepoint firms.

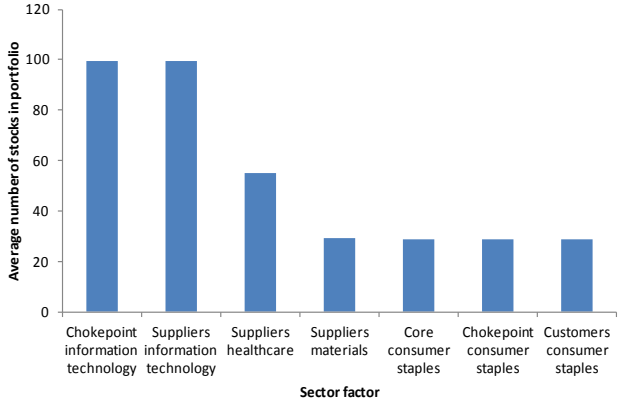
Neutralizing sector and size

When conducting stock selection, it is important to compare 'apples to apples'. As we discussed in Wang, et al [2013], neutralizing country, sector and size generally improves factor performance. Also, as we have seen in the previous sections, industries and sectors are represented in very different numbers within the supply chain. Some sectors are also natural suppliers, while others are natural customers to the overall economy. This must be taken into account when using our graph-metrics for stock selection. In line with intuition, our methodology is to control for market cap and sector exposure. Note that our factors still use the full cross-section supply chain information.

Backtesting all our factors by sector

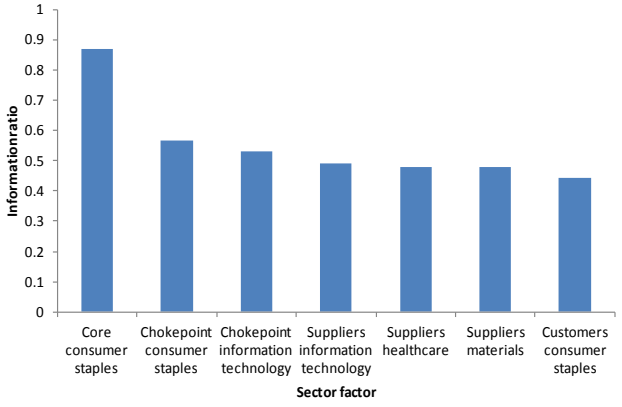
Once we neutralize our chokepoint factor by size, we can implement it within each of the ten sectors. The sector portfolios tend to be highly-concentrated, given the limited number of stocks within most sectors (see Figure 62). The performance of the chokepoint signal is fairly strong in all sectors, in particular in the consumer staples sector (see Figure 63).

Figure 62: Number of stocks in each sector (size-neutral chokepoint factor)



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

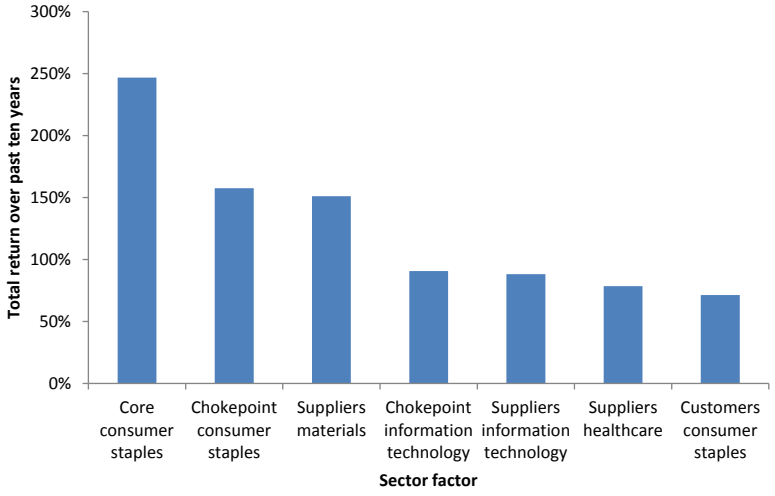
Figure 63: Sharpe ratio (size-neutral chokepoint factor)



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Given the homogenous nature of the companies within the consumer staples sector, and the reliance on the supply-chain network, most of the network centricity factors (e.g., core, bridge/chokepoint and customer) produce strong returns (see Figure 63 and Figure 64).

Figure 64: Total return of each portfolio over the past ten years (size neutral only)



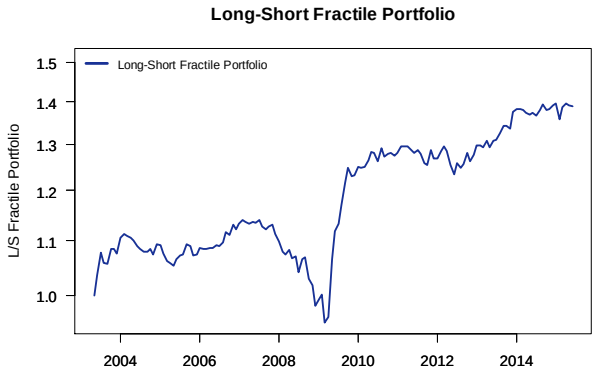
Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Backtesting a chokepoint portfolio

Intuitively, chokepoints are of systemic importance. This makes them even more important than major suppliers or customers, regardless of sectors. Similar to Wang, et al [2013], we neutralize both size and sector for our chokepoint factor. We note that this portfolio is formed by taking a long position in the highest number of shortest-path chokepoints and a short position in the smallest number of shortest-path chokepoints.

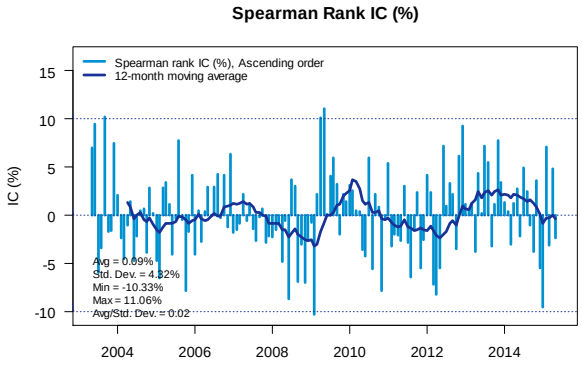
The chokepoint factor has performed well in the long term, albeit with a big drawdown during the 2008 global financial crisis and a quick recovery (see Figure 65 and Figure 70). This result is in line with the systemic importance of these companies within the supply chain. The position they hold within the economy reduces their risk in normal times, as they are logistically-hedged with a diverse client and supplier base that must flow through them. However, if all of these suppliers and customers start behaving in a correlated fashion, then these chokepoint companies are particularly exposed to any systemic factors. This, in turn, will cause these important chokepoints to enter into distress scenarios, thus exacerbating the systemic risk.

Figure 65: Cumulative performance of the long-short chokepoint portfolio (sector and size neutral)



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

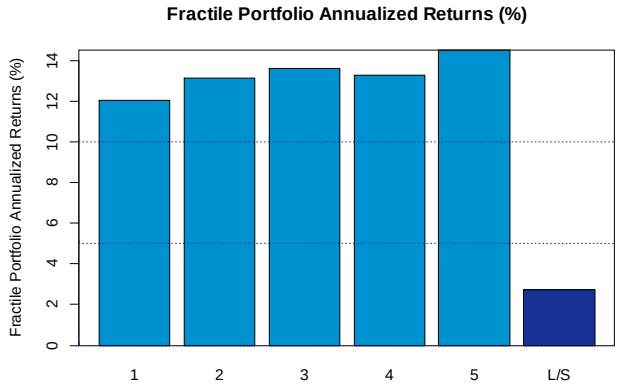
Figure 66: Rank IC – chokepoint (sector and size neutral)



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

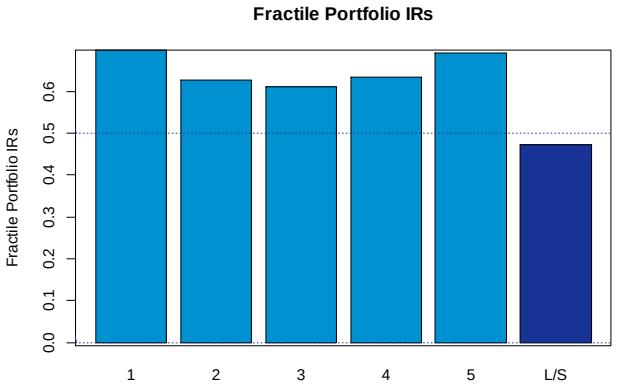
Chokepoints present a few specific characteristics, compared to both other supply network factors and traditional quant factors. While the payoff pattern is linear, the slope is quite modest (see Figure 67). This translates into a small average IC (see Figure 66). The signal performs better in risk-adjusted terms (see Figure 68). The true edge of chokepoint factor, however, lies in its relative stability. Our chokepoint signal has a two-way monthly turnover of only 50% per month (see Figure 69).

Figure 67: Expected annualized returns of each quintile



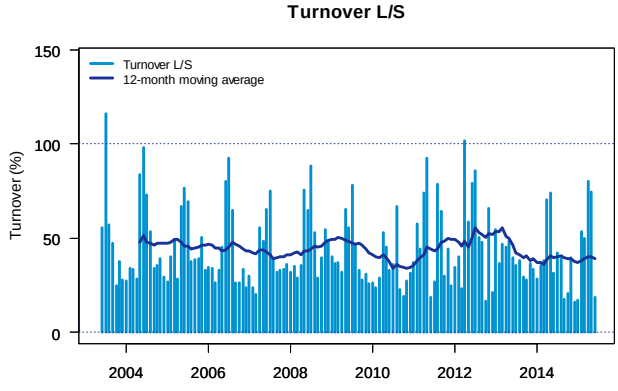
Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 68: Quintile information ratios



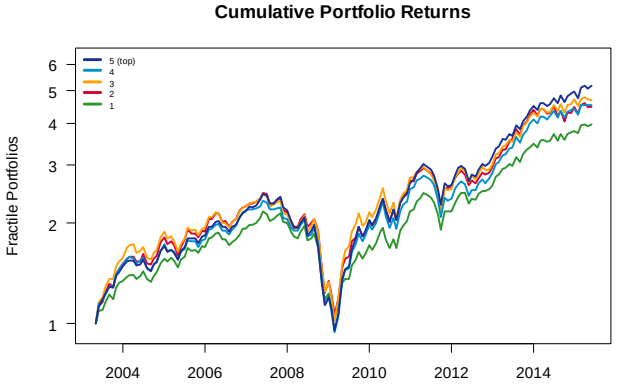
Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 69: Portfolio two-way monthly turnover



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Figure 70: Cumulative performance of each quintile



Source: Compustat, FactSet, Russell, S&P, Thomson Reuters, Deutsche Bank Quantitative Strategy

Other Organic Networks

Future research

Asset ownership network[11]

These networks present a special structure reminiscent of genetic networks: just as asset owners hold stocks, genes are linked to attributes. Genes are correlated when they link to similar attributes. Similarly, attributes correlate when they are 'owned' by the same genes. The same crowding behavior appears within asset holders. This allows the use of cutting edge clustering algorithms on the asset ownership graph to identify which asset managers tend to hold the same stocks, and which stocks tend to be owned by the same asset managers. Just as with the supply chain, this approach goes beyond the local properties of a single company or asset owner. Another distinction from supply chain networks is that shocks may transmit faster in the asset ownership network, as the major ownerships are well-defined, and it is more difficult to hold shocks to assets from the market compared to holding operational shocks to a company's raw materials, production, inventory and delivery routes.

Licensing network

The licensing network can be treated as a subset of supply chain networks, as the flow on the directed edges is composed of product licenses, patents, intellectual property and technology approvals. Due to the cost and the time to set up such strategic relationships, we expect such networks to be more stable over the long-term horizon compared to regular supply chain networks, and also with longer lead-lag momentum.

Joint venture network

The subject company would jointly own a separate company with one or more relationship companies. These relationships are not directed. The joint venture not only affects all owner companies, but we also expect some subtle issues among the owners, such as control rights.

Integrated product network

Companies in integrated product offering relationships agree to bundle standalone products/services together as one offering to the market. There is no money or value exchanged upfront, and costs, risks and profits are shared. It would be interesting to see how different these relationships are from horizontal integrations.

Research collaboration networks

Research collaboration networks are industry-specific – common between science companies and technology companies. This designation is applicable for products in development, which are not marketed.

[11] Please refer to our previous research on institutional ownership alpha (see Jussa, et al [2014]).

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Appendix 1

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