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The effect of operational slack, diversification, and vertical relatedness on the stock market reaction to supply chain disruptions

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ABSTRACT

This paper empirically examines whether operational slack, business diversification, geographic diversification, and vertical relatedness influence the stock market reaction to supply chain disruptions. The results are based on a sample of 307 supply chain disruptions announced by publicly traded firms during 1987–1998. Our analysis shows that firms with more slack in their supply chain experience less negative stock market reaction. The extent of business diversification has no significant effect on the stock market reaction. Firms that are more geographically diversified experience a more negative stock market reaction. We find that firms with a high degree of vertical relatedness experience a less negative stock market reaction. These results have important implications on how firms design and operate their supply chains to mitigate the negative effect of supply chain disruptions.

1. Introduction

Supply chain disruptions have become a critical issue for many firms. Performance setbacks because of disruptions frequently make headlines in popular business press. Recent examples include shortages of components experienced by Ericsson due to fire-related damage at a supplier plant (Latour, 2001); parts shortages crimping Motorola's ability to meet demand for camera phones (Drucker, 2003); and shut down of several Japanese automobile plants because of earthquake-related damage to the manufacturing facilities of a sole supplier of piston rings (Chozick, 2007). Recent surveys also show that firms are very concerned about supply chain disruptions. Accenture's study of 151 supply chain executives finds that 73% of the executives indicate that their firms experienced supply chain disruptions in the past 5 years, and 48% expect that the risk of disruptions will increase over the next 3 years (Ferrer et al., 2007). A survey by FM Global of more than 600 financial executives finds that 25% of the executives consider supply chain risks, more than any other risks, as having the greatest potential to disrupt profitability and revenue growth (Smyrlis, 2006).

Academics and practitioners have begun to address three major issues related to supply chain disruptions. First, Kilgore (2003), Stauffer (2003), Chopra and Sodhi (2004), Kleindorfer and Wassenhove (2004), Kleindorfer and Saad (2005), Sheffi (2005), Tang (2006), and Craighead et al. (2007), among others, identify and discuss the primary drivers of disruptions and factors that can influence the probability or frequency of disruptions. Second, others have examined the economic consequences of disruptions. Using a sample of publicly announced supply chain disruptions, Hendricks and Singhal (2003, 2005a,b) document that the stock market reacts very

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negatively to disruptions, and that disruptions result in much lower profits and sales, and higher costs. Anecdotal evidence also indicates that disruptions can be costly (e.g., Latour, 2001; Rice and Caniato, 2003). Third, others analyze and discuss supply chain strategies and structures that have the potential to reduce the frequency of disruption or mitigate the negative economic consequences of disruptions (Lee, 2004; Kleindorfer and Saad, 2005; Sheffi, 2005; Tang, 2006; Tomlin, 2006; Swafford et al., 2006; Ketchen and Hult, 2007; Craighead et al., 2007). Although there is much discussion in both the academic and the practitioner literature on strategies that firms can use to reduce the frequency or mitigate the negative impact of disruptions, there is little rigorous empirical evidence to support the effectiveness of these strategies.

The primary objective of this paper is to empirically test the effectiveness of different supply chain strategies in mitigating the negative economic consequences of supply chain disruptions. We address the issue that given that a firm has experienced a disruption, how different aspects of a firm's supply chain strategies influence the economic consequences of disruptions. As in Hendricks and Singhal (2003), we use the stock market reaction to disruption announcements as our measure of the economic consequences of disruptions. Our analysis is based on a sample of 307 disruptions that were experienced and announced by publicly traded firms during 1987–1998. We examine three strategies that have been widely discussed in the literature as strategies that can help firms deal effectively with disruptions. The first is whether the extent of operational slack influences the stock market reaction to disruptions. Many researchers and practitioners argue that operational slack can mitigate the negative impact of disruptions as slack provides flexibility and resources to deal with disruptions. We test this conjecture using sales over assets, cash-to-cash cycle, and days of inventory as proxies of operational slack. Consistent with our expectations, we find that firms that have operational slack in their supply chain experience less negative stock market reaction.

The second strategy that we examine is the role of diversification in mitigating the negative economic effects of disruptions. Many argue that diversification provides risk reduction benefits that can mitigate the impact of disruptions. Diversification can also provide options that could be valuable in dealing with disruptions. For example, a geographically diversified firm may have the option to switch production should disruption occurs in one part of its supply chain. On the other hand, geographically diversification increases supply chain complexity which could make it harder for a firm to react to supply chain disruptions. We use the Business Segment and Geographic Segment data from Compustat to measure the extent of business and geographic diversification of our sample firms, and relate this to the stock market reaction. Contrary to our expectations, we find that the extent of business diversification does not mitigate the negative effect of supply chain disruptions on stock prices. We find that firms that are more geographically diversified experience a more negative stock market reaction.

Finally, we test whether the degree of vertical relatedness of a firm influences the stock market reaction to disruptions. A high degree of vertical relatedness means that the firm uses more of its own input for producing its products and services, and/or uses more of its own output as its input. Vertical relatedness can be viewed as the extent of internal control the firm has over its inputs and outputs. We use the Business Segment data from Compustat, the input–output data by industry sectors from the U.S. Bureau of Economic Analysis, and the concept of relatedness developed by Fan and Lang (2000) to develop a measure of the degree of vertical relatedness. We find that firms with a high degree of vertical relatedness experience a less negative stock market reaction.

The next section develops our hypotheses. Section 3 describes the sample collection. Section 4 describes how we compute the various variables used in our analysis. Section 5 presents our empirical results and robustness checks. The final section summarizes the paper.

2. Hypotheses

This section presents the hypotheses that relate the stock market's reaction to operational slack, diversification, and vertical relatedness. Many researchers and practitioners argue that the severity of the negative economic impact of supply chain disruptions is related to the extent of operational slack with which a firm operates. In the last decade or so many firms have focused on improving the efficiency of their supply chains by eliminating slack and redundancy. However, there now seems to be the recognition that the focus on efficiency may have made supply chains more brittle. This may have had a negative effect on a firm's capabilities to deal with disruptions. Lee (2004) highlights that cost efficiency comes with a hidden cost should a major disruption happen, and that firms must balance the notion of cost efficiency with adaptability and flexibility. Kleindorfer and Saad (2005) argue that extreme leanness and efficiency can result in increasing vulnerability to supply chain disruptions and negatively affect a firm's ability to deal with disruptions. A recent report by Deloitte Consulting (2007) discusses "The Efficiency Backlash" to highlight how the focus on efficiency has made supply chains more prone to disruptions. Stauffer (2003) argues that since lean operations can also be more vulnerable to disruptions, firms must balance the need for efficiency against the risks and expected cost of disruptions. The above discussion seems to suggest that compromising on efficiency by building some slack may mitigate the negative effect of disruptions.

Many have highlighted the risk of operating with lean inventories should disruptions happen. Chopra and Sodhi (2004) argue that although operating with very low inventory levels can decrease the chances of overstocking, it can simultaneously amplify the negative impact of supply chain disruptions. The recent shutdown of several Japanese automobile plants due to earthquake-related damage at Riken Corp., a sole supplier of piston rings, highlights the danger of single sourcing as well as the just-in-time philosophy of keeping as little inventory on hand as possible (Chozick, 2007). Stauffer (2003), Smyrlis (2006), and Ferrer et al. (2007) mention that in many cases the risks inherent in operating with low levels of inventory can be the primary causes of supply chain disruptions.

To deal with supply chain disruptions, Chopra and Sodhi (2004) suggest that firms need to build reserves of inventory, capacity, and redundant suppliers. Tang (2006) highlights the need to build strategic stock of critical components as one of the robust strategies for dealing with disruptions. Craighead et al. (2007) argue that the severity of the disruptions is inversely related to the presence of recovery capabilities. Kleindorfer and Saad (2005) and Lee (2004) suggest that backup systems, excess capacity, multiple suppliers, inventory buffers, and flexibility can lower the probability of disruptions as well as reduce the negative impact of disruptions. Bourgeois (1981) highlights the importance of organizational slack to deal with different types of disruptions.

The above discussion suggests that the focus on making supply chains efficient may have left little slack in the supply chain to deal with disruptions. Furthermore, many of the recommendations for dealing with supply chain disruptions suggest that firms need to build more slack to respond effectively to disruptions. Accordingly, our hypothesis is:

H1. *The stock market's reaction to supply chain disruption announcements will be less negative for firms that operate with higher operational slack.*

Our next hypothesis concerns the relationship between corporate diversification and the stock market's reaction to supply chain disruption. We focus on two aspects of diversification: (1) business diversification which refers to the extent to which a firm operates in different lines of businesses; (2) geographic diversification which refers to the extent to which the firm operates in different countries or regions of the world. An extensive body of research examines various aspects of business and geographic diversification including why firms choose to diversify, the costs and benefits of diversification, trends in diversification, and the extent to which diversification creates or destroys value. A comprehensive review of this research is beyond the scope of this paper and the interested reader is referred to Lang and Stulz (1994), Fan and Lang (2000), Denis et al. (2002), Goerzen and Beamish (2003), and Bowen and Wiersema (2005). Our interest is limited to the issue of whether diversification affects the stock market's reaction to disruptions.

With respect to business diversification we expect that the less diversified the firm, the more negative will be the stock market reaction. There are a number of reasons for this. First, the economic impact of a disruption can be more severe for a less diversified firm as the profitability of such a firm is likely to be critically dependent on the performance of the single or limited lines of businesses that the firm operates in. Thus, any disruption is likely to affect a larger fraction of the total business for a less diversified firm. Second, a less diversified firm may take longer to recover from disruptions as it may have limited abilities to raise the resources needed to deal with disruptions. In a more diversified firm, managers have the flexibility to shift funds and resources internally from businesses not affected by the disruptions to businesses that are affected by the disruptions, and thus respond to disruptions faster and more effectively. Furthermore, because of the coinsurance effect, the ability to raise capital to deal with disruptions can increase with diversification (Lewellen, 1971). Our hypothesis is:

H2. *The stock market's reaction to supply chain disruption announcements will be less negative for firms that have higher levels of business diversification.*

The argument for the relationship between geographic diversification and the stock market's reaction to supply chain disruption is not as clear. Allen and Pantzalis (1996), Buckley and Casson (1998), Chowdhry and Howe (1999), Pantzalis et al. (2001) and Allayannis et al. (2001), among others, argue that having plants in multiple countries enables firms to not only align their costs and revenues, but also to achieve operational flexibility by shifting production among those locations. Such operational flexibility and options can mitigate the negative effect of disruptions. Huchzermeier and Cohen (1996) argue that with geographic diversification a firm can build operational flexibility. Their analytical model is focused on the issue of managing global operations under exchange rate uncertainty, and how locating facilities in different countries can improve the value of the firm. They indicate that under a globalization strategy a firm is likely to have multisite operations and multisupplier sourcing, which provide firms with the options of rearranging their production should disruptions affect the operations in one country or region.

Craighead et al. (2007) argue that supply chain density can affect the severity of the economic impact from disruptions. Their notion of supply chain density is based on the extent of geographical dispersion of supply chains. Although they do not develop a precise measure of density, they argue that supply chain density and the economic severity of a supply chain disruption should be positively related as the chances of a disruption affecting many parts of a supply chain are higher with a more dense supply chain than with a less dense supply chain. Kilgore (2003) argues that supply chain disruption risk increases when a firm's manufacturing and distribution resources are concentrated in few locations, facilities, suppliers, and transportation routes.

Recent papers on strategies for dealing with disruptions also suggest that the extent of geographic diversification can be an important factor in influencing the severity of the economic impact of disruptions. Chopra and Sodhi (2004) suggest that a firm can mitigate the negative effect of disruptions by avoiding concentration of facilities and using decentralizing capacity. Kleindorfer and Saad (2005) advocate that diversification should be extended to include facilities, sourcing options, and logistics. Tang (2006) argues that building a flexible supplier base is a robust strategy for dealing with supply chain disruptions, and that geographic diversification could enable the firm to build a flexible supply base. Tang (2006) highlights the case of how Li and Fung's supplier network of nearly 4000 suppliers offers them the flexibility to shift production and sourcing among different countries should a disruption occur in a particular country.

Alternatively, Craighead et al. (2007) argue that the severity of a supply disruption could be related to the supply chain complexity, where complexity is defined in terms of the number of nodes and the extent of flows among the nodes. Choi and Krause (2006) conceptualize the various dimensions of supply base complexity, and conjecture that increased complexity increases risk and decreases supply chains responsiveness. Rice and Caniato (2003), Stauffer (2003), Chopra and Sodhi (2004), Tang (2006), and Deloitte Consulting (2007), among others, argue that global supply chains are more complex and more vulnerable to disruptions, may take longer to recover from disruptions, and suffer more economic damage from disruptions. Geographic diversification can indicate that the firm has longer and stretched supply chains, and hence, more complex and difficult to manage supply chains. A growing body of literature has highlighted the importance of supply chain integration in improving the performance of supply chains and responding to disruptions (Narasimhan and Jayaram, 1998; Frohlich and Westbrook, 2001; Narasimhan and Kim, 2002; Vickery et al., 2003; Das et al., 2006). Integration is likely to be more difficult and challenging in supply chains that are geographically diversified. This lack of integration can negatively impact the ability of firms to respond to disruptions. Thus, one can argue that higher geographic diversification may result in a more negative reaction to supply chain disruptions.

Based on the above discussion, arguments could be made in either direction. Therefore, our two-tailed hypothesis is limited to:

H3. *The stock market's reaction to supply chain disruption announcements will have a non-zero association with the degree of geographic diversification.*

Our final hypothesis concerns the relation between the extent of vertical relatedness and the stock market reaction to disruptions. Many researchers and practitioners argue that outsourcing has made supply chain more susceptible to disruptions, and that firms that depend more on outsourcing are likely to experience more negative economic impacts from supply chain disruptions (Chopra and Sodhi, 2004; Kleindorfer and Wassenhove, 2004; Kleindorfer and Saad, 2005; Sheffi, 2005; Tang, 2006; Craighead et al., 2007). A higher degree of outsourcing means that the firm is generally less vertically related. With outsourcing, a firm gives up partial control of its supply chains. In the event of supply chain disruptions, firms that outsource more will have increased difficulties in coordinating with external partners to recover from the disruptions. Miller (1998) suggests that firms with negative exposure to input prices can create operational flexibility by either developing in-house capacity to produce inputs, or through vertical integration of key suppliers. In a recent article in the Wall Street Journal, Aeppel (2006) highlights that some firms are increasing their extent of vertical integration. This is partially driven by volatility in prices and partially by the difficulty in securing raw materials and components. He cites Mittal Steel Co. and Boeing as examples of firms that either use long-term supply contracts with suppliers or have acquired suppliers to secure long-term supply of raw materials. This guarantee of long-term supply minimizes the chance of disruptions due to shortages. In general, one would expect that a more vertically related firm exerts more control over its inputs or outputs, and more likely to recover quickly from a supply chain disruption. Thus, our hypothesis is:

H4. *The stock market's reaction to supply chain disruption announcements will be less negative for firms that have higher levels of vertical relatedness.*

3. Sample description

Our sample of supply chain disruptions is compiled from announcements in the *Wall Street Journal* (WSJ) and the *Dow Jones News Service* (DJNS) (see Hendricks and Singhal, 2005b for more details on how the sample is compiled). The sample covers a 12-year period from 1987 to 1998. Key words used in the search include: delay, shortfall, shortage, manufacturing, production, shipment, delivery, parts, components, and other relevant phrases. We read the full text of articles that contained combinations of these keywords, and exclude the following types of announcements:

- Articles in which firms did not actually announce supply chain disruptions. Some articles discussed in general why certain industries were facing supply chain problems.
- Announcements relating to firms with insufficient daily stock price information available from CRSP (Center for Research in Security Prices). This excludes firms that are not publicly traded on the New York, American, or Nasdaq stock exchanges.
- Earnings announcements that mention supply chain disruptions as one of the main reasons for the level of reported earnings because such announcements are likely to provide information about other factors that are affecting firm performance.
- Non-earnings announcements that mention supply chain disruptions as one of many issues as these announcements are contaminated and confounded by other factors that could affect the stock market reaction.

To test our hypotheses, we need firm-level and industry-level accounting data to construct the independent and control variables (details of variable constructions are explained later). To be included in our sample, a firm must have data in the Compustat database on book value of equity, total debt, net sales, inventory, accounts receivable, accounts payable, cost of goods sold, and property, plant and equipment. We also require that our sample firms have sales data for the business and geographic segments in the Compustat Segment database. With these data requirements, our final sample consists of 307 announcements. Two examples of disruption announcements included in our sample are:

> "Boeing pushing for record production, finds parts shortages, delivery delays", *Wall Street Journal*, June 26, 1997.

"Apple Computer Inc. Cuts 4th-period Forecast Citing Parts Shortages, Product Delays", *Wall Street Journal*, September 15, 1995.

Our analysis focuses on the firm that makes the supply chain disruption announcement. The announcement is an acknowledgement by the announcing firm that it has suffered a disruption. We do not include the suppliers or the customers of the announcing firm in our analyses unless the firm's suppliers or customers also make an announcement that they have experienced a disruption.

Out of the 307 announcements, 44 announcements (14% of the sample) did not give any information on who is responsible for the disruption. Of the remaining 263 announcements 235 announcements give a single source of responsibility and 28 gave multiple sources of responsibilities for the disruption. Out of the 307 announcements, 115 announcements (37% of the sample) attribute the disruption responsibility solely to internal sources, 61 announcements (20% of the sample) attribute the responsibility solely to customers, and 47 announcements (15% of the sample) attribute the responsibility solely to suppliers. Many announcements also give reasons for the disruptions. The four primary reasons are part shortages (72 announcements), order changes by customers (41 announcements), production problems (33 announcements), and ramping and rollout (31 announcements). Other descriptive statistics of the sample are given in Table 1, which we discuss later in the paper.

4. Variable constructions and definitions

This section discusses the construction of the dependent, independent, and control variables that we use in our analysis.

4.1. Measuring the stock market reaction to announcements of supply chain disruptions

The dependent variable in our regression analysis is the stock market reaction to supply chain disruption announcements. We use the event-study methodology to estimate the market reaction. This methodology provides a rigorous approach to estimate the market reaction to announcements, while adjusting for both industry and market-wide influences on stock prices (see Brown and Warner, 1985 and MacKinlay, 1997 for a review of this methodology)). These adjusted returns are referred to as abnormal returns. Consistent with most studies that examine the stock market reaction to announcements, we estimate abnormal returns around the date of the announcement of disruptions, which includes the day of the announcement and the day before the announcements. We use two different methods to estimate the abnormal returns.

Our first method uses the market model to estimate the abnormal returns (see Brown and Warner, 1985 for a description of this model). The market model posits a linear relationship between the return on a stock and the return on the market portfolio over a given time period. This relationship is expressed as:

$$r_{it} = \alpha_i + \beta_i r_{mt} + \varepsilon_{it} \quad (1)$$

where r_{it} is the return of stock i on day t, r_{mt} is the return of the market portfolio on day t, α_i is the intercept of the relationship for stock i, β_i is the slope of the relationship for stock i, and ε_{it} is the error term for stock i on day 0. The term $(\beta_i r_{mt})$ is the return to stock i on day t that can be attributed to market-wide movements, while ε_{it} is the unexplained part of the return that captures the effect of firm specific events on day t. For each firm, we estimate $\hat{\alpha}_i$ and $\hat{\beta}_i$ using ordinary least squares regression over an estimation period of 200 trading days, with the equally weighted CRSP index as a proxy for the market portfolio. Each firm's estimation period ends ten trading days prior to the announcement date. A minimum of 40 return observations in the estimation period is required for the estimation procedure. The abnormal return (A_{it}) for stock i on day t from the market model is:

$$A_{it} = r_{it} - \hat{\alpha}_i - \hat{\beta}_i r_{mt}, \quad (2)$$

where r_{it} is the actual return on stock i on day t. For each sample firm, we estimate the abnormal returns on the day of the announcement and the day before the announcement and sum these up to get the two-day abnormal return.

Our second method estimates abnormal returns using an approach that does not rely on estimation periods or choice of underlying abnormal return-generating models. This approach is based on factors that explain the cross-section of expected returns and uses a matched-control group and buy-and-hold returns to generate the abnormal returns. Models of cross-section expected returns estimate abnormal returns as the difference between the return on the sample firms and the return on an appropriate benchmark, where the benchmark is chosen based on the similarity of its characteristics to that of the sample firm. Researchers have used different methods to identify the appropriate benchmark (see Fama, 1998 and Kothari and Warner, 1997 for a review of this literature). We use the portfolio-matched method to estimate abnormal returns. In this method, every month all firms listed on CRSP are assigned to one of 210 portfolios, each of which is formed on the basis of size (as measured by the market value of equity), the ratio of market value of equity to book value of equity, and prior performance. These variables have been shown to predict the cross-sectional expected returns (Fama and French, 1996; Carhart, 1997; Jegadeesh and Titman, 1993). Based on the announcement date, each sample firm is in one of the 210 portfolios, and the remaining firms in that portfolio serve as benchmarks for the sample firm. The abnormal return, A_{it}, is the difference between the return on the sample firm and the average return on the other firms in the sample firm's benchmark portfolio:

$$A = r_{it} - r^{b}_{it} \quad (3)$$

where r^{b}_{it} is the average return on day t for the firms that are in the sample firm's benchmark portfolio. Lyon et al. (1999)

and Hendricks and Singhal (2005a) provide details of implementing this method.

4.2. Measures of operational slack

One of our primary hypotheses is that the stock market reaction to disruption announcements will be influenced by the extent of operational slack with which a firm operates. We use three different measures of operational slack. Two of these slack measures can be considered as measures that are internal to the firm, and the third can be considered as a measure of slack across the supply chain. We use industry-adjusted measures of operational slack, where each sample firm's industry is defined as all firms that have the same primary three-digit SIC code as that of the sample firm. All measures of operational slack are based on information reported in the most recent fiscal year ending prior to the announcement date.

Chopra and Sodhi (2004), Kleindorfer and Saad (2005), and Tang (2006), among others, argue that slack in the form of excess capacity can be effective in dealing with disruptions. We use the ratio of annual sales to net property, plant, and equipment (SOP) as a measure of slack. To control for differences in SOP across industries, we first take the difference between an individual firm's SOP and the industry mean SOP and then normalize this difference by the industry mean. All else being equal, firms with high industry-adjusted SOP are more likely to operate with tight capacity (or little slack). Given our hypothesis about operational slack and the stock market reaction, we expect that firms with high industry-adjusted SOP will experience a more negative stock market reaction.

Our second measure of operational slack is days of inventory. Many have argued that the economic impact of supply chain disruptions will be more negative for firms operating with low levels of inventories. We measure days of inventory as 365 times the ratio of the average of beginning and ending inventory to cost of goods sold. For each sample firm, we compute its industry-adjusted days of inventory by first taking the difference between the sample firm's days of inventory and the industry mean days of inventory. We then normalize this difference by the industry mean. The predicted sign of industry-adjusted days of inventory is positive.

Cash-to-cash cycle (also referred to as trade cycle) is often used as an indicator of the leanness of supply chains. For example, Dell Computer's negative cash-to-cash cycle is often cited as an example of the leanness and efficiency of Dell's supply chain. We use cash-to-cash cycle as our third measure of operational slack. Cash-to-cash cycle is measured as

$$\begin{aligned}\text{Cash-to-cash cycle} = {} & \text{days of inventory} \\ & + \text{days of accounts receivables} \\ & - \text{days of accounts payables}\end{aligned}$$

where days of inventory = 365(average inventory/annual cost of goods sold); days of accounts receivables = 365(average accounts receivables trade/annual sales); days of accounts payables = 365(average accounts payable/annual cost of goods sold); All else equal, a leaner supply chain will have a lower cash-to-cash cycle. We use two methods to control for industry differences in cash-to-cash cycles. First, we compute the industry-adjusted cash-to-cash cycle by taking the difference between industry mean cash-to-cash cycle and the cash-to-cash cycle of the firm. Second, we compute industry-adjusted normalized cash-to-cash cycle as the industry-adjusted cash-to-cash cycle divided by the sum of industry mean days of inventory, accounts receivables, and accounts payables. A higher value of industry adjusted cash-to-cash cycle is indicative of leaner supply chains. Since we expect that leaner supply chains will experience more negative stock market reaction from disruptions, the predicted sign of the industry adjusted cash-to-cash cycle is negative.

4.3. Measure of business diversification

We use information from the Compustat Business Segment data to measure business diversification. Under Rule 14 of the Financial Accounting Standards Board (FASB 14), public firms are required to disclose significant business segment information. A business segment is generally considered significant if it accounts for more than 10% of the total sales, profits, or assets of the firm.

The measure of business diversification is based on computing the Herfindahl Index for each firm based on the sales reported by the different business segments. We compute the business Herfindahl Index (B_{Hrf}) as the summation of the square of the ratio of the individual business segment's annual sales to the total sales of the firm:

$$B_{\text{Hrf}} = \sum_{i=1}^{N} \left(\frac{S_i}{S}\right)^2$$

S_i is the annual sales of the ith business segment; S is the total annual sales of the firm; N is the number of business segments reported by the firm

We measure business diversification, B_{Diver}, as $1 - B_{\text{Hrf}}$. Single segment firms will have B_{Hrf} equal to 1 and B_{Diver} equal to 0 whereas multi-segment firms will have B_{Hrf} less than 1 and B_{Diver} greater than 0 but less than 1. Firms that have a high degree of business diversification will have low values of B_{Hrf} and, therefore, high values of B_{Diver}. Since we hypothesize that the market's reaction to supply chain disruption announcements will be less negative for firms that have higher levels of business diversification, the predicted sign of B_{Diver} on abnormal returns is positive.

4.4. Measure of geographic diversification

Firms are required to report information about geographic areas that account for more than 10% of total sales, profits, or assets of the firm. There is no requirement by FASB regarding groupings for geographic operations. Compustat defines geographic segments based upon operations at the country level, and limits the number of geographic segments to four including the domestic segment. Export sales by the domestic segment are not treated as foreign sales. We adopt the same approach as that used for business diversification to measure geographic diversification. Based on the sales in the different geographic segments, we compute the geographic Herfindahl Index (G_{Hrf}) as the summation of the square of the ratio of the individual geographic segment's annual sales to the total sales of the firm:

$$G_{\mathrm{Hrf}} = \sum_{i=1}^{N} \left(\frac{S_i}{S} \right)^2$$

S_i is the annual sales of ith geographic segment; S is the total annual sales of the firm; N is the number of geographic segments reported in Compustat

We measure geographic diversification, G_{Diver}, as $1 - G_{\mathrm{Hrf}}$. Firms operating in single geographic segment will have G_{Hrf} equal to 1 and G_{Diver} equal to 0 whereas firms operating in multiple geographic segments will have G_{Hrf} less than 1 and G_{Diver} greater than 0 but less than 1. Firms that have a high degree of geographic diversification will have low values of G_{Hrf} and, therefore, high values of G_{Diver}.

Our hypothesis about geographic diversification is based on issues related to supply chain flexibility, density, and complexity. It will be useful to link these issues to our measure of geographic diversification. Huchzermeier and Cohen (1996) discuss flexibility in terms of globalization. Geographic diversification is a measure of how global is the footprint of the firm. In the context of the model of Huchzermeier and Cohen (1996), a more geographically diversified firm is more flexible. Craighead et al. (2007), Kilgore (2003), Chopra and Sodhi (2004) argue that supply chain concentration or density can affect the severity of the negative impact from disruptions. Concentration can be measured at the micro level by examining the location of each and every facility of a firm. It can also be measured at the macro level by looking at the different countries that a firm operates in. Given the availability of data, we chose to proxy this using data on different geographic segments that a firm operates in. Finally, Craighead et al. (2007), Kilgore (2003), Chopra and Sodhi (2004), and Choi and Krause (2006) argue that global supply chains are more vulnerable to disruptions and the negative impact of disruptions can be more severe. More global supply chains will be more geographically diversified.

We note that there are alternate proxies of measuring business and geographic diversification. One proxy is to count of the number of business or geographic segments that a firm operates in. Another proxy is to use the concentration ratio which is the ratio of the sales (assets) of the largest business or geographic segment to total sales (assets). While these two measures are sometimes used in the literature, the most commonly used measure is the Herfindahl Index as it considers the size of the various business or geographic segments in estimating the extent of diversification.

4.5. Measure of vertical relatedness

We use the concept of vertical relatedness developed by Fan and Lang (2000) to measure the extent of vertical relatedness of our sample firms. A firm is said to be vertically related if some of its businesses can use the products and services of its other businesses, or some of its businesses supply outputs that are inputs to its other businesses. Relatedness measures the extent to which the firm has internal control over its inputs and outputs.

To compute relatedness, Fan and Lang (2000) use the commodity flow data in the "Use Table" of the Benchmark Input–Output (IO) account for the U.S. economy that is published every five years by the U.S. Bureau of Economic Analysis. The accounts are based on data collected from economic censuses conducted by the U.S. Census Bureau. The "Use Table" is a matrix containing the value of goods flowing between each pair of roughly 500 industries. For each pair of industry i and j (i and j can be the same), the Use Table reports V_{ij}, the dollar value of i's output required to produce industry j's total output. Dividing V_{ij} by the dollar value of industry j's total output gives v_{ij}, the dollar value of industry i's output used to produce one dollar worth of industry j's output. For example, a value of v_{ij} of 0.10 indicates that 10% of industry j's input comes from industry i. Higher values of v_{ij} indicate a higher degree of vertical relatedness of industry i into industry j. Conversely, v_{ji} represents the dollar value of industry j's output used to produce one dollar worth of industry i's output. We note that v_{ij} and v_{ji} can be interpreted as forward and backward relatedness coefficients, respectively.

It would be ideal to use firm-specific data to compute the vertical relatedness at the firm level. Since this type of data is not available, we follow Fan and Lang's (2000) approach of using industry level IO coefficients and the business segment data to construct the relatedness coefficients at the firm level. For each firm-year in Compustat between 1979 and 1997, Fan and Lang (2000) estimate the forward and backward relatedness coefficients between the firm's primary business segment and each of its secondary business segments, where the largest business segment in terms of sales is denoted as the primary segment and remaining segment(s) as secondary segment(s). For each firm, we use the primary business segment as our base to compute V_f (the forward relatedness coefficient) and V_b (backward relatedness coefficient) as follows:

$$V_f = v_{ii} + \frac{\sum_{j=1}^{N} v_{ij} S_j}{S_i}$$

$$V_b = v_{ii} + \frac{\sum_{j=1}^{N} v_{ji} S_i}{S_i}$$

where S_i is the total sales of the primary segment i, S_j is the total sales of the secondary segment j, and N is the total number of secondary business segments.

V_f represents the fraction of the output from the primary segment that is used internally and V_b represents the fraction of the primary segment's input that is from internal sources. The average of V_f and V_b is our proxy of the vertical relatedness of the firm. Appendix A provides an example on how the vertical relatedness of a firm is computed.

As discussed earlier, a high level of vertical relatedness indicates that firms exert more control over their inputs and outputs, and hence, are less dependent on external supply chain partners. This decreased dependency on an external supply chain gives firms more flexibility in the event of a disruption. Hence, we expect that the vertical relatedness measure is positively associated with the stock market reaction to disruptions that is firms that have higher vertical relatedness will experience less negative abnormal returns.

4.6. Firm and industry specific control variables

We use the following variables as controls in our analysis as previous research has used these variables to explain the stock market reaction to disruptions (see Hendricks and Singhal, 2003). All variables are based on information reported in the most recent fiscal year ending prior to the announcement date:

- Firm size – measured as the natural logarithm of sales in the most recent fiscal year ending prior to the announcement date.
- Book-to-market ratio – the proxy for growth potential, measured as the ratio of book value of equity to the market value of equity. Firms with low growth prospects have high book-to-market ratios.
- Debt-to-equity ratio – measured as the ratio of the book value of debt to the sum of the book value of debt and the market value of equity.

In addition, we control for the industry competitiveness and the effect of a disruption announcement on the sample firm's industry.

- Industry competitiveness – measured as 1 minus the industry Herfindahl index. The Herfindahl index for an industry is defined as the sum of the squared fraction of industry sales of each firm that is in the industry. For each sample firm, we compute the Herfindahl index of its industry using sales of all firms with the same primary three-digit SIC code as that of the firm announcing the disruption. A higher (lower) value of 1 minus the Herfindahl index means a more (less) competitive industry.
- Value weighted industry return – is the two-day return over the portfolio comprised of all other firms with the same primary three-digit SIC code as the sample firm.

4.7. Descriptive statistics of the sample

Table 1 presents statistics on the sample based on the most recent fiscal year completed before the date of the disruption announcement. The median observation represents a firm with market value of equity of $240.39 million, total assets of $169.83 million, and sales of $189.77 million. The median debt ratio is 8.3%.

The median industry-adjusted ratio of sales to net property, plant and equipment (SOP) is −0.29, industry-adjusted days of inventory is −0.25, and industry-adjusted cash-to-cash cycle is 11.74 days. These statistics indicate that relative to their industry, the median sample firm has lower SOP, has lower inventories, and has a shorter cash-to-cash cycle. The Pearson correlation coefficient between industry-adjusted SOP and industry-adjusted days of inventory is −0.05; industry-adjusted SOP and industry adjusted cash-to-cash cycle is 0.04; and industry-adjusted days of inventory and industry adjusted cash-to-cash cycle is 0.09. The correlations among the three measures of operational slack are low and insignificantly different from zero.

Table 1
Descriptive statistics for the sample of 307 announcements of supply chain disruptions.

Variables	Mean	Median
Market value of equity (millions US $)	5601.55	240.39
Total assets (millions US $)	10087.95	169.83
Sales (millions US $)	8279.65	189.77
Debt ratio	15.2%	8.3%
Industry-adjusted ratio of sales to property plant and equipment	−0.09	−0.29
Industry-adjusted days of inventory	−0.08	−0.25
Industry-adjusted cash-to-cash cycle	5.70	11.74
Industry-adjusted cash-to-cash cycle (normalized)	0.01	0.06
Business diversification (1 − business Herfindahl index)	0.11	1
Geographic diversification (1 − geographic Herfindahl index)	0.20	0.04
Vertical relatedness coefficient	0.057	0.029

Sample statistics are based on the most recent fiscal year completed before the date of the disruption announcement.

Nearly 83 firms (just over 27% of our sample) have multiple business segments. The average sample firm has 1.51 segments, and the maximum number of business segments in our sample is 6. Our measure of business diversification (1 − business Herfindahl index) has a mean value of 0.11, which indicates that on average our sample firms have low levels of business diversification. Nearly 163 firms (just over 53% of our sample) operate in multiple geographic areas. The average sample firm operates in 1.98 geographic areas, and the maximum number of geographic areas in our sample is 4. Our measure of geographic diversification (1 − geographic Herfindahl index) has a mean value of 0.20, which indicates that on average our sample firms have reasonable levels of geographic diversification. The correlation between operating and geographic diversification is −0.01, insignificantly different from zero.

4.8. Summary results for the stock market reaction to disruptions.

We estimate the abnormal returns on the day of the announcement and the day before the announcement. As mentioned earlier, we use two different methods to estimate the abnormal returns. Our first method estimates abnormal returns from the market model (see Eqs. (1) and (2)). The results indicate that the stock market reacts negatively to supply chain disruptions The mean abnormal return on the day before the announcement is −7.31% (t-statistic of −39.04) and the median abnormal return is −4.56% (Z-statistic of the Wilcoxon signed rank test is

−11.49). The abnormal returns on day 0 are also negative. The mean abnormal return is −1.82% (t-statistic of −8.84) and the median abnormal return is −0.66% (Z-statistic of the Wilcoxon signed rank test is −2.94). The two-day (day before the announcement and day of the announcement) mean abnormal return is −9.12% (t-statistic of −33.86) and the median abnormal return is −6.48% (Z-statistic of the Wilcoxon signed rank test is −12.25), both significantly different from zero at the 1% level. Nearly 80% of the abnormal returns are negative.

The results from the portfolio matching method (the second method – see Eq. (3)) are very similar. The two-day mean (median) abnormal return is −9.01% (−6.73%), significantly different from zero at the 1% level. Nearly 84% of the sample firms experienced negative abnormal returns.

5. Empirical results

We use Ordinary Least Squares regressions to test our hypotheses on operational slack, diversification, and vertical relatedness. Table 2 reports the results for two different models. In both models, the dependent variable is the two-day abnormal return from the market model. To remove the potential influence of any outliers, Table 2 reports the results after symmetrically trimming the dependent variable at the 1% level in each tail. The results for the full sample without trimming are very similar. The difference between Models 1 and 2 is the calculation of industry-adjusted cash-to-cash cycle. Model 1 uses the industry-adjusted cash-to-cash cycle measured as the difference between the industry mean cash-to-cash cycle and the cash-to-cash cycle of the firm. In Model 2 the industry-adjusted cash-to-cash cycle measure is normalized by dividing it by the sum of industry mean inventory cycle, industry mean accounts receivable collection cycle, and industry mean accounts payable deferral cycle.

The results partially support our prediction that the higher the operational slack, the less negative will be the stock market's reaction to disruption. We use three different measures of operational slack. The estimated coefficient of the industry-adjusted ratio of sales to property, plant, and equipment (SOP) is negative and statistically significant at the 2.5% level in a one-tail test. All else being equal, firms with high industry-adjusted SOP are more likely to operate with tight capacity (or little slack). As discussed earlier, lack of slack makes it harder to recover from disruptions, which can increase the severity of the negative effects of disruptions. The negative coefficient of industry-adjusted SOP indicates that the stock market reacts more negatively to disruption announcements by firms that have low slack.

Many have argued that operating with lean inventories or low days of inventory can negatively affect the ability of the firm to deal with disruptions. Thus, one would expect that firms with high days of inventory (relative to their industry) will experience a less negative stock market when disruptions occur. Although the coefficient of the industry-adjusted days of inventory is negative, the coefficient is insignificantly different from zero.

Firms with smaller cash-to-cash cycles are generally operating with leaner supply chains and have less slack, which could make it harder to recover from disruptions. Our definition of industry-adjusted cash-to-cash cycle implies that the higher this number, the smaller is the firm's cash-to-cash cycle and operating slack. Thus, we expect to see a negative correlation between industry-adjusted cash-to-cash cycle and the stock market's reaction to disruptions. As predicted, the coefficient in Model 1 is negative and statistically significant at the 2.5% level in a one-tailed test. When we use the normalized form of the industry-adjusted cash-to-cash cycle (see Model 2), the coefficient is still negative but significant at the 5% level in a one-tailed test.

We use three variables to test the relation between diversification and the stock market reaction to disruptions. Our first variable is an indicator variable that has a value 1 if the firm operates in multiple business segments and in different geographic regions. The other variables are

Table 2
Ordinary least squares regression results using a sample of 301 supply chain disruption announcements. The dependent variable is the two-day cumulative abnormal returns using the market model.

Independent variables	Predicted sign	Model 1	Model 2
Intercept	?	−0.282 (−5.21) a	−0.283 (−5.21) a
Industry-adjusted ratio of sales to property, plant, and equipment	–	−0.015 (−2.26) b	−0.014 (−2.29) b
Industry-adjusted days of inventory	+	−0.0002 (−0.04)	−0.0001 (−0.17)
Industry-adjusted cash-to-cash cycle	–	−0.0001 (−1.96) b	
Industry-adjusted cash-to-cash cycle normalized	–		−0.026 (−1.85) c
Business and geographic diversification (indicator variable)	+	0.012 (0.61)	0.013 (0.57)
Business diversification	+	−0.002 (−0.05)	0.003 (0.06)
Geographic diversification	?	−0.063 (−1.93) d	−0.062 (−1.91) d
Vertical relatedness	+	0.175 (2.09) b	0.182 (2.18) b
Firm size		0.016 (5.60) a	0.016 (5.75) a
Book-to-market ratio		0.073 (3.79) a	0.074 (3.83) a
Debt-to-equity ratio		−0.049 (−1.45)	−0.052 (−1.50)
Industry competitiveness		0.075 (1.28)	0.075 (1.28)
Value-weighted industry returns		0.241 (0.97)	0.244 (0.99)
Number of observations		301	301
Model F value		8.11 a	8.07 a
R squared		25.26%	25.17%
Adjusted R squared		21.15%	22.05%

Significance levels (one-tailed tests): a, 1% level; b, 2.5% level; c, 5% level; significance levels (two-tailed tests): d, 10% level.

the extent of business diversification and geographic diversification.

Although the coefficients of the indicator variable of diversification and business diversification are positive, they are insignificantly different from zero. The coefficient of geographic diversification is negative and significant at the 10% level in a two-tail test. We had argued that geographic diversification offers operational flexibility that could be useful in switching production in case of disruptions, and that firms with such flexibility will experience a less negative stock market reaction. We had also argued that that geographic diversification increases the complexity of the organizational structure, which could make it more difficult to coordinate in the event of a supply chain disruption. This difficulty of coordination could actually worsen the economic impact of disruptions, and hence more geographically diversified firm will experience a more negative stock market reaction. The evidence seems to support the complexity argument.

As predicted, the estimated coefficient of vertical relatedness is positive and statistically significant at the 2.5% level in a one-tail test, indicating that firms that have high vertical relatedness experience less negative abnormal returns compared to firms with low vertical relatedness. Recall that a vertically related firm will exert more control over its inputs or outputs, and is more likely to recover quickly from a supply chain disruption. The stock market reaction for such firms is less negative.

With respect to the control variables we find that both smaller firms and firms with high growth rates experience more negative abnormal returns. Capital structure (debt-to-equity ratio) has little effect on the abnormal returns. These findings are similar to those in Hendricks and Singhal (2003). Finally, the industry competitiveness measure and the value-weighted industry returns that are used to control for the remaining industry effects do not have significant impact on the abnormal returns

It is possible that the strategies of operational slack, geographic diversification, and vertical relatedness could be interrelated because these strategies may have common elements, and firms could be adopting these strategies simultaneously. If this is the case, then there may be multicollinearity among our independent variables, which could decrease the reliability of the estimated regression coefficients. We investigate the presence of multicollinearity by examining the Variance Inflation Factor (VIF) values of the independent variables. The VIF values for operational slack variables are less than 1.25, for geographic diversification it is 1.34, and for vertical relatedness it is 1.12. In fact none of the VIF values for all the variables in our regression model are greater than 2.5. Kutner et al. (1996) recommend looking at the largest VIF value. A value greater than 10 is an indication of potential multicollinearity problems. Given that the VIF values we observe are less than 2.5, multicollineraity does not seem to be an issue with our sample. Furthermore, the absolute magnitude of the correlation coefficients between operational slack, geographic diversification, and vertical relatedness is less than 0.20.

For the two models in Table 2, the *F*-values are greater than 7.0 indicating that both models are significant at the 1% level or better. Adjusted R^2 values are around 22%, which are reasonable given that our regressions are based on cross-sectional data, and are comparable to those observed in previous studies (see, for example, Francis et al., 1996; Klassen and McLaughlin, 1996; Hendricks and Singhal, 1997, 2003; Chen et al., 2003; Mitra and Singhal, 2008; Girotra et al., 2007). In these papers the adjusted R^2 values are generally less than 20% for cross-sectional regressions using stock market reaction as the dependent variable.

5.1. Sensitivity and exploratory analyses

To explore the sensitivity of our results, we repeat our analyses replacing the abnormal returns from the market model with the abnormal returns from the portfolio matching method (see Table 3). These results are similar to the results presented in Table 2.

Table 3
Ordinary least squares regression results using a sample of 301 supply chain disruption announcements.

Independent variables	Predicted sign	Model 1	Model 2
Intercept	?	−0.255 (−4.86) a	−0.255 (−4.86) a
Industry-adjusted ratio of sales to property, plant, and equipment	–	−0.008 (−1.32)	−0.008 (−1.34)
Industry-adjusted days of inventory	+	0.002 (0.32)	0.001 (0.24)
Industry-adjusted cash-to-cash cycle	–	−0.0001 (−2.31) b	
Industry-adjusted cash-to-cash cycle normalized	–	−0.029 (−2.13) b	
Business and geographic diversification (indicator variable)	+	0.012 (0.61)	0.010 (0.56)
Business diversification	+	−0.002 (−0.06)	−0.001 (−0.04)
Geographic diversification	?	−0.055 (−1.72) d	−0.054 (−1.70) d
Vertical relatedness	+	0.152 (1.87) c	0.160 (1.97) b
Firm size		0.016 (5.80) a	0.016 (5.75) a
Book-to-market ratio		0.070 (3.77) a	0.072 (3.83) a
Debt-to-equity ratio		−0.040 (−1.25)	−0.043 (−1.31)
Industry competitiveness		0.047 (0.83)	0.047 (0.82)
Value-weighted industry returns		0.151 (0.63)	0.155 (0.65)
Number of observations		301	301
Model *F* value		8.00 a	7.92 a
R squared		25.02%	24.82%
Adjusted *R* squared		21.90%	21.69%

The dependent variable is the two-day buy-and-hold abnormal returns using the portfolio matching method.
Significance levels (one-tailed tests): a, 1% level; b, 2.5% level; c, 5% level; significance levels (two-tailed tests): d, 10% level.

In the case of geographic diversification, we have presented offsetting arguments where the arguments for flexibility argues for a less negative impact and the arguments for complexity argues for a more negative impact. Based on announcements during 1987–1998 our results support the complexity argument. During the review process one of the reviewers raised the issue that post September 2001, firms that are more geographically diversified would have a more challenging time in dealing with disruptions as security concerns could delay the flow of material and products across countries. This could affect the relationship between geographic diversification and the stock market reaction to disruption announcements. We have 30 post-September 2001 observations (disruptions announced in 2002–2003) but we do not have data on the vertical relatedness ratios for these observations. Since vertical relatedness ratio is a significant variable in our regression analyses, running the regression with the post September 2001 observations but without the relatedness ratio variable to test for the effect of geographic diversification leads to an omitted variable problem. This could bias our estimates of the coefficient of geographic diversification. However, to shed some light on this issue, we estimate the abnormal returns for the disruptions announced during the post September 2001 period and compare it with the abnormal returns for the disruptions announced during 1987–1998. The mean abnormal return of the 30 disruption announcements during the post September 2001 period is −6.92%, which is insignificantly different from −9.12%, the mean abnormal return of the disruption announcements during 1987–1998. The results show that the magnitude of the abnormal returns for the two-time period are not significantly different from each other.

We find that firms with more operational slack in their supply chain experience less negative stock market reaction. Operational slack could be more valuable in an efficiency driven environment versus a responsiveness driven environment. It is plausible that under normal conditions (i.e., absence of supply chain disruptions) the stock market penalizes a supply chain operating in an efficiency driven environment for having excessive operational slack. However, the same operational slack can mitigate the negative impact of a supply chain disruption in an efficiency driven environment. In the case of a responsiveness driven environment, the presence of operational slack may be rewarded during normal operations but may not be that much more valuable in the case of a disruption because the slack is already there.

To test if the stock market reaction differs across efficiency and responsiveness driven environments, we use operating margin (operating profits/sales where operating profits is sales minus cost of goods, and selling, general, and administration costs) to segment our sample firms into two groups. A firm is considered to be operating in an efficiency driven environment (responsiveness driven environment) if its operating margin is below (above) the median operating margin of its industry, where a firm's industry is defined as all firms with the same primary three-digit SIC code as that of the firm announcing the disruption. We ran our basic regressions of Table 2 with an indicator variable that has a value 1 if the firm operates in a responsiveness driven environment and 0 otherwise. The coefficient of the indicator variable is insignificantly different from zero, indicating that the stock market reaction to disruptions is not influenced by whether a firm operates in efficiency or responsiveness driven environments.

We also explore whether the stock market reaction is moderated by the source of responsibility for disruptions. Based on the information in the announcement, we partition the responsibility for disruptions into the following four mutually exclusive categories:

Disruption attributed solely to internal sources.
Disruption attributed solely to customers.
Disruption attributed solely to suppliers.
Other sources including multiple sources of responsibility and no source indicated.

For each source of responsibility, we start with Model 1 in Table 2 (our baseline regression) and add an indicator variable that has a value 1 if the responsibility belongs to that source and 0 otherwise. The coefficient of this indicator variable is an estimate of by how much the stock market reaction for the source of responsibility differs from the stock market reaction for all other sources of responsibilities considered together (the intercept). We repeat this four times for the four different responsibility categories. The results indicate that disruptions caused by customers are viewed more negatively by the market. The additional penalty associated with disruptions caused by customers is approximately 2.74%, significantly different from zero at the 5% level in a two-tailed test. The adjusted R^2 value with the customer responsibility indicator variable is 22.93%.

We also explore whether the stock market reaction is moderated by the reason for disruptions. Based on the information in the announcement, we partition the reasons for disruptions into the following five mutually exclusive categories:

Disruption due to parts shortages.
Disruption due to order changes by customers.
Disruption due to production problems.
Disruption due to ramp-up and roll out problems.
Other reasons and no reason given.

For each reason category, we start with Model 1 in Table 2 (our baseline regression) and add an indicator variable that has a value 1 if the reason belongs to that category and 0 otherwise. The coefficient of this indicator variable is an estimate of by how much the stock market reaction for this reason differs from the stock market reaction for all other reasons considered together (the intercept). We repeat this five times for the five different reason categories. The results indicate that disruptions due to order changes by customers and production problems are viewed more negatively by the market. The additional penalty associated with disruptions due to order changes by customer is 3.71% (significantly different from zero at the 2.5% level in a two-tailed test) and is 4.19% for disruptions due to production problems ((significantly different from zero at the 2.5% level in a two-tailed test) The adjusted R^2 value with the order changes by customers indicator variable is 23.27%, and is 23.42% with production problems indicator variable.

6. Summary, discussion, and future research

The severe negative economic consequences of supply chain disruptions have increased the criticality of managing disruptions. Although there is much discussion in both the academic and the practitioner literature on strategies that firms can use to mitigate the negative impact of disruptions, there is little rigorous empirical evidence to support the effectiveness of these strategies. In this paper, we empirically test whether operational slack, business diversification, geographic diversification, and vertical relatedness influence the stock market reaction to supply chain disruptions. Our analysis is based on 307 supply chain disruptions made by publicly traded firms during 1987–1998.

Our analysis shows that firms with operational slack in their supply chains experience less negative stock market reaction. Contrary to our expectations, we find that the extent of business diversification has no significant effect on the stock market reaction. Firms that are more geographically diversified experience a more negative stock market reaction. We find that firms with a high degree of vertical relatedness experience a less negative stock market reaction.

The empirical analyses presented in this paper are important for a number of reasons. First, as mentioned earlier, there is little empirical evidence to judge the effectiveness of strategies that are claimed to be effective in dealing with supply chain disruptions. Much of the justification is based on case studies and analytical models. Supplementing the intuition and insights from case studies and analytical models with rigorous empirical data provides a stronger rational for prescribing strategies to deal with disruptions.

Second, many of the strategies for dealing with disruptions question the wisdom of strategies that are usually considered best practices in the recent past (Tang, 2006; Craighead et al., 2007). Some examples of such best practices include outsourcing, single sourcing, reducing the supplier base, and focusing on improving the efficiency of supply chain. Interestingly, many now argue that these best practices are constraining and hampering the ability of firms to deal with disruptions. By analyzing whether operational slack, diversification, and the extent of vertical relatedness affect the stock market's reaction to disruptions, we shed light on whether the best practices of the past are associated with more severe negative impacts due to disruptions.

Third, there are costs associated with implementing strategies to enhance a firm's capability to deal with disruptions. By empirically estimating the benefits associated with such strategies, we provide a basis for understanding the cost–benefit analyses of these strategies.

Finally, firms have to worry about balancing stock price performance during normal operations as well as when it experiences supply chain disruptions. For example, in an efficiency driven environment, the market may reward firms that are operating with little operational slack. Yet the lack of operational slack can hurt the firm when it experiences a disruption. Firms will have to strike a balance by focusing on areas where lack of slack can really hurt in case of a disruption. Firms may also need to explain to investors the need for building slack so that investors accurately reflect the value of slack in their valuations.

There are a number of directions for future research. First, it could be useful to consider other strategies that potentially influence the stock market reaction to supply chain disruptions. In particular, it would be interesting to document how the structure and footprint of the supplier base (for example, the extent of single sourcing, number of suppliers, dispersion of suppliers, and supplier capabilities) can attenuate or mitigate the negative economic consequences of disruptions. RFID and ERP systems have the potential of increasing collaboration among supply chain partners as well as increasing visibility and traceability of supply chain performance issues (Delan et al., 2007; Ngai et al., 2007; Hendricks et al., 2007; Wezel et al., 2006), which could influence the frequency of disruptions as well as the negative consequences of disruptions. It would be of interest to see how a firm's information technology capabilities can moderate the stock market reaction to disruptions. It would also be interesting to explore whether post September 2001 disruptions are viewed differently by the stock market. As mentioned earlier, this is a limitation of our paper as we do not have the data to fully analyze this issue. It is plausible that processes implemented by various governments and firms to deal with security concerns may actually increase the frequency of disruptions and amplify the negative effect of disruptions as security issues may further delay the flow of material and products across countries.

Second, our focus has been on understanding the effectiveness of different strategies in mitigating the negative economic consequences of supply chain disruptions. Another important aspect of managing disruptions is to reduce the frequency or probability of experiencing disruptions. It would be useful to collect data on the frequency of supply chain disruptions and link these to different drivers of disruptions as well as strategies that can reduce the probability of disruptions. It would also be useful to gather more detailed information about the nature of supply chain disruption including major versus minor, isolated versus widespread, disruption happening at a company owned facility versus that at a supplier. Such characteristics of disruption may shed more light on the role of supply chain strategies for mitigating the negative impact on stock performance. Since such information is not publicly available, this may require detailed case studies as well as working closely with companies that have experienced disruptions to collect the detailed information on the characteristics of the disruptions. Habermann and Shah (2008) provide a conceptual framework and measuring instruments for capturing information about the nature of supply chain disruptions using surveys.

Third, our analysis focuses on the firm that makes the announcement of a supply chain disruption. The announcement is an acknowledgement by the announcing firm that it has suffered a disruption. It is possible that suppliers and customers of the announcing firm could be affected by the disruption even though suppliers and customers do not make a disruption announcement. An interesting issue would be to estimate how the disruption experienced by one firm affects its supply chain partners. The customer information database from Compustat and other data sources could be used to identify the primary customers and suppliers of the firm that has announced a disruption, and the effect of disruptions on their stock price performance could be estimated. This would shed light on how tightly linked are the various supply chain partners and would help distangle the effect of disruptions on the various links in the supply chain.

Appendix A. Computing the vertical relatedness of a firm

This appendix illustrates the computation of the vertical relatedness measure of a firm using the example of Zytec Corp., which experienced a supply chain disruption on June 14, 1995. To compute the relatedness ratio we use Zytec's 1994 business segment information from Compustat. In 1994 Zytec reported total sales of $133.186 million and that it operated in two segments. Its primary business segment was electronic components (SIC 3679), which reported sales of $126.924 in 1994. It had one secondary business segment – computer maintenance and repair (SIC 7378), which reported sales of $6.262 million in 1994.

Fan and Lang (2000) use the commodity flow data in the "Use Table" of the Benchmark Input–Output (IO) to compute v_{ij}, the dollar value of industry i's output used to produce one dollar worth of industry j's output. They estimate that v_{ii} is 0.198 for i representing the industry with SIC 3679. This indicates that for firms operating in SIC 3679, 19.8% of its input comes from its own industry. Fan and Lang (2000) also estimate that v_{ij} is 0.027 with i representing SIC 3679 and j representing SIC 7378. We define the forward relatedness coefficient, V_f, as:

$$V_f = v_{ii} + \frac{\sum_{j=1}^{N} v_{ij} S_j}{S_i}$$

where S_i is the total sales of the primary segment i; S_j is the total sales of the secondary segment j; and N is the total number of secondary business segments.

Using the values of v_{ii}, v_{ij}, and the sales for the primary segment and secondary segments into the equation, our estimate of Zytec's forward relatedness coefficient is 0.1997.

Fan and Lang (2000) also estimate that v_{ji} is 0.002 with j representing SIC 7378 and i representing SIC 3679. We define the backward relatedness coefficient, V_b, as:

$$V_b = v_{ii} + \frac{\sum_{j=1}^{N} v_{ji} S_i}{S_i}$$

Using the values of v_{ii}, v_{ji}, and the sales for the primary segment and secondary segments into the equation, our estimate of Zytec's forward relatedness coefficient is 0.2004.

The average of average of V_f and V_b gives the vertical relatedness ratio of Zytec as 0.2001.

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