

**The Effect of Supply Chain Disruptions on Long-term Shareholder Value,
Profitability, and Share Price Volatility**

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I. Overview and summary

Senior executives are devoting increasing attention to effective supply chain management. Although much of their focus in the past was on wringing efficiencies and cost out of supply chains, more recently they are becoming worried about supply chain disruptions as security concerns, terrorist attacks, and the transformation of supply chains into lean, complex, and globally dispersed entities has increased the risks of disruption. While most executives can see the value proposition of improving efficiencies and reducing costs, many executives are having a hard time getting a handle on the economic consequences of supply chain disruptions. This may have prevented many executives from making investments and changes that could have mitigated the risk of disruptions.

This report presents the findings and evidence on the long-term effects of supply chain disruptions on corporate performance. The findings are based on a study of nearly 800 instances of supply chain disruptions experienced by publicly traded firms. It provides estimates on the effect of disruptions on long-term shareholder value, profitability, and share price volatility (a measure of the risk of the firm). This report presents the most comprehensive and detailed analysis published to date on the performance effects of supply chain disruptions. The analysis uses objective data and rigorous estimation methodologies to isolate the effect of disruptions on different measures of corporate performance.

The key results are:

- Firms suffering from supply chain disruptions experience between 33 to 40% lower stock returns relative to their benchmarks over a three year time period that starts one year before and ends two years after the disruption announcement date.

- Disruptions increase the risk of the firm. The share price volatility in the year after the disruption is 13.50% higher when compared to the volatility in the year before the disruption.
- Disruptions have a significant negative effect on profitability. After adjusting for industry and economy effects, the average effect of disruptions in the year leading to the disruption announcement is:
 - 107 % drop in operating income
 - 7 % lower sales growth
 - 11 % growth in cost
- Disruptions have a debilitating affect on performance as firms do not quickly recover from disruptions. Firms continue to operate for at least two year at a lower performance level after experiencing disruptions.
- Disruptions have a negative across the board effect on stock price, profitability, and share price volatility. It does not matter who caused the disruption, what was the reason for disruption, what industry a firm belongs to, or when the disruption happened - disruptions devastate corporate performance.

The evidence discussed in this report has major implications for senior executives:

- It underscores the need as to why senior executives must be aware of the primary sources of disruptions in their supply chains, what can be done to mitigate the risks of disruption, and take proactive actions to mitigate risks. Disruptions, even if infrequent, have the potential to destroy value that might have been painstakingly created over years.

- Recent corporate governance legislation makes senior executives more responsible for forecasts of performance and protection of shareholder value. Since supply chain disruptions are often unforeseen and unexpected and can have a material impact on performance, senior executives can open themselves to litigation from disgruntled shareholder as well as questions from regulators.
- Although the focus on making supply chains more efficient and lean makes economic sense, senior executives must recognize that lean and efficient supply chains face higher risk of disruptions. There is a direct relationship between efficiency and risk. Firms can no longer afford to focus solely on cost reduction. Major supply chain investments and initiatives must also take into consideration how these investments and changes affect the risks of supply chain disruptions.
- In many instances supply chain investments and initiatives should be undertaken not because they reduce costs but because they increase the reliability and responsiveness of supply chains. Such investments and initiatives should be viewed as insurance against avoiding destruction of corporate performance should disruptions happen and they should be justified on this basis and not cost savings.

II. Introduction

There is increased awareness and recognition among managers, consultants and academics that supply chain performance is increasingly important to business success. Firms are more dependent upon their supply chains networks to deliver value. In most industries supply chain performance has become a much more strategic and competitive issues as it directly affects a firm's ability to generate revenue, manage cost, improve asset productivity, and enhance customer satisfaction. In recent years, supply chains have also become more vulnerable to disruptions. While some of this vulnerability has been due to major one-time events such as 9/11, the west-coast port strike in 2002, the 2003 Northeast blackout, and other acts of nature, many of the recent supply chain disruptions have been due to the inability of firms to better manage and control their internal as well external supply chain networks.

Although the negative link between supply chain disruptions and corporate performance has been extensively talked about in the business and academic publications, hard evidence on this linkage is very limited. Much of the evidence that is offered is anecdotal. More recently, supply chain woes at Cisco (inventory write-off), Sony (shortage of critical components), Nike (inventory buildup), and Ericsson (parts shortages) have been used to make the case that supply chain disruptions have the potential to cause significant value destruction. While such anecdotes and case studies are useful to get attention, they do not provide the hard and objective evidence that many senior executives are looking for to better understand the value creation potential of supply chains and to make decisions about the initiatives and investments they should undertake to improve the effectiveness of their supply chain.

This report presents the findings and evidence on the long-term effects of supply chain disruptions on corporate performance. The evidence is based on a study of nearly 800 instances

of supply chain disruptions experience by publicly traded firms. It builds upon an earlier report that had the limited objective of estimating the short-term shareholder value effects of disruptions. This study estimates the effect of supply chain disruptions on long-term shareholder value, profitability, and share price volatility. The key results of this more extensive and comprehensive analyses of supply chain disruptions are:

- Firms suffering from supply chain disruptions experience 33 to 40% lower stock returns relative to their benchmarks over a three year time period that starts one year before and ends two years after the disruption announcement date. Much of the underperformance is observed in the year before the announcement, the day of the announcement, and the year after the announcement. One way to judge the economic significance of this level of underperformance is the fact that on average stocks have gained 12% annually in the last two decades. Even if a firm experiences one major supply chain disruption every 10 years, the annual return would be close to 8-9%, which represent a significant shareholder value loss when one takes into account the effect compounding over long-time periods.
- Disruptions increase share price volatility. Share price volatility in the year after the disruption is 13.50% higher when compared to the volatility in the year before the disruption. Such increase in volatility could undermine investor confidence as well as raise the cost of capital for the firm. It can also make a firm's shares a less attractive currency for acquisitions as potential targets may be less inclined to do deals that depends on volatile share prices.

- Disruptions have a significant negative effect on profitability. After adjusting for industry and economy effects, the average effect of disruptions in the year leading to the disruption is:
 - 107 % drop in operating income
 - 114 % drop in return on sales
 - 93 % drop in return on assets
 - 7 % lower sales growth
 - 11 % growth in cost
 - 14 % growth in inventories
- During the two-year time period after the disruption announcement, the changes in operating income, sales, total costs, and inventories are still negative.
- Disruptions have an across the board negative effect on shareholder value, profitability, and risk. It does not matter who caused the disruption, what was the reason for disruption, or what industry a firm belongs to.
- The effect of disruptions is more negative for smaller firms than larger firms.
- Firms do not quickly recover from disruptions. It can take at least two years or more to reach the pre-disruption performance levels.

This report represents the most comprehensive and detailed analysis published to date of the performance effects of supply chain disruptions. It systematically documents the performance effects by

- Using objective data that is available in the public domain.

- Using state-of-the-art and rigorous estimation methodologies to isolate the effect of disruptions.
- Conducting extensive sensitivity analyses and statistical testing to validate the results.

Although the primary focus of this report is on documenting the evidence, it also discusses some of the root causes of supply chain disruptions and what firms can do to mitigate the frequency and adverse consequences of disruptions.

The evidence and discussion in this report should be of interest to

- CEOs and CFOs, who are responsible for improving and sustaining shareholder value and profitability in their firms.
- CIOs and VPs of Supply Chains, who are responsible for supply chain strategy development as well as implementation of supply chain management processes and technologies to improve over-all business performance of the firm.
- Consultants and technology providers who provide expertise and infrastructure to improve the reliability and responsiveness of supply chains.

III. Why estimate the effects of supply chain disruptions on corporate performance?

There are a number of reasons why firms should worry about the effect of supply chain disruptions on corporate performance:

- Much of the emphasis in the recent past has been on how to make the supply chain more efficient. Many firms have made significant progress on this dimension. But, there is a limit to how much efficiency can be wrung out from supply chains. Firms must now focus their effort on maintaining and preserving the gains that have been achieved, and to do this they must ensure disruption free performance of supply chains.
- Investments in technology, new levels of collaboration and cooperation among supply chain partners, revisiting the logic of old strategies, and implementing new business models are some of the actions that firms will have to contemplate to mitigate the chances of disruptions. These changes will require senior management support, involvement, and commitment. To get this involvement, senior management must clearly see the effect supply chain management can have on business results, profits, revenues, costs, and shareholder value. Documenting the effects of disruptions on corporate performance can help bring about this awareness.
- Security concerns can make supply chain prone to disruptions. In the post-September 11, 2001 world, many countries have initiated efforts to ensure that imports do not contain material that is explosive, radioactive, or biologically malignant. Complying with new security procedures and processes could mean longer lead times, more uncertainty, more administrative work, and

higher costs. In particular, increased lead times and uncertainty can make supply chains more vulnerable to disruptions. Awareness of the cost of disruptions can help firms evaluate and make trade-offs between alternative approaches to deal with security issues.

- Recent corporate governance legislation makes senior executives more responsible for forecasts of performance and protection of shareholder value. Since supply chain disruptions are often unforeseen and unexpected and can have a material impact on performance, senior executives can open themselves to litigation from disgruntled shareholder as well as to questions from regulators. Securities and Exchange Commission wants publicly traded firms to report unplanned events such as supply chain disruptions within two working days of their occurrence. Dealing with these regulatory issues may require changes in the way firms do business, investments in new technologies, and reconsideration and/or reversal of past decisions and strategies. The economic effect of disruptions can help senior executives better evaluate these decisions.

IV. Methodology and approach

The evidence presented in this report is based on an analysis of more than 800 supply chain disruptions that were publicly announced during 1989-2000. These announcements appeared in the Wall Street Journal and/or the Dow Jones News Service, and were about publicly traded companies that experienced production or shipping delays. Some examples of such announcements are:

- “*Sony Sees Shortage of Playstation 2s for Holiday Season*”, *The Wall Street Journal*, September 28, 2000. The article indicated that because of component shortages, Sony has cut in half the number of PlayStation 2 machines it can manufacture for delivery.
- “*Motorola 4th Quarter Wireless Sales Growth Lower Than Order Growth*”, *The Dow Jones News Service*, November 18, 1999. In this case Motorola announced that its inability to meet demand was due to the shortage of certain types of components and that the supply of these components is not expected to match demand sometime till 2000.
- “*Boeing Pushing for Record Production, Finds Parts Shortages, Delivery Delay*,” *The Wall Street Journal*, June 26, 1997. The article discusses reasons for the parts shortages, the severity of the problems, and the possible implications.
- “*Apple Computer Inc. Cuts 4th period Forecast Citing Parts Shortages, Product Delays*,” *The Wall Street Journal*, September 15, 1995. Apple announced that earnings would drop because of chronic and persistent part shortages of key components and delays in increasing production of new products.

The performance effects of the above mentioned instances of supply chain disruptions are estimated by examining performance over a three year time period starting one year before the disruption announcement date and ending two years after the disruption announcement date.

Two stock market based metrics are used in the analysis:

- Shareholder returns as measured by stock returns that include changes in stock prices as well as any dividends declared.
- Share price volatility.

The effect of disruptions on profitability is examined using the following measures:

- Operating income (Sales minus cost of goods sold minus selling and general administration)
- Return on Sales (Operating income divided by sales)
- Return on Assets (Operating income divided by total assets)
- Sales
- Costs (sum of cost of goods sold and selling and general administration cost)
- Total assets
- Total inventory

To control for industry and economy affects that can influence changes in the above performance measures, the performance of the disruption experiencing firms is compared against benchmarks of firms that are in the same industry with similar size and performance characteristics. Appendix I, II, and III briefly describe the methodology used for estimating stock returns, share price volatility, and profitability changes, respectively, due to disruptions.

V. Long-term shareholder value effects of supply chain disruptions

Figure 1 depicts the shareholder value effects on the day supply chain disruptions are publicly announced. The effects that can be attributed to disruptions is estimated by comparing the stock returns of disruptions experiencing firms against four different benchmarks that serve to control for normal market and industry influences on stock returns.

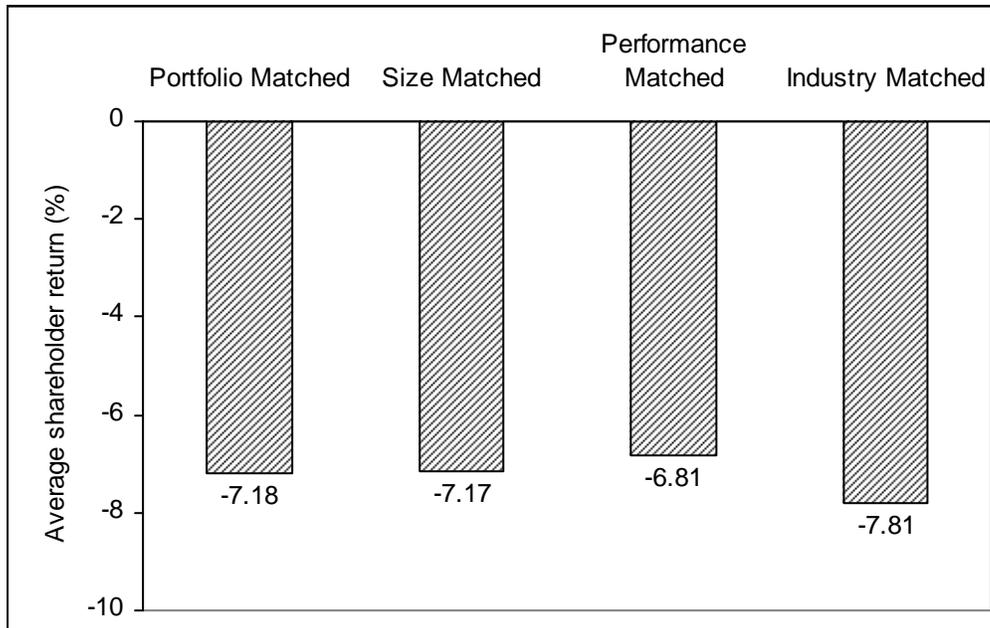


Figure 1: The average shareholder return on the day information about disruptions is publicly announced. Portfolio, size, performance, and industry matched are different set of benchmarks used to estimate the relative stock price performance of the firms that experience disruptions.

The evidence indicates that supply chain disruptions are viewed very negatively by the market. On average shareholders of disruption experiencing firms lose:

- 7.18% relative to the benchmark that consists of the portfolio of all firms that have similar prior-performance, size, and market to book ratio of equity to the disruption experiencing firm (portfolio matched benchmark).

- 7.17% relative to the firm that has similar prior-performance and market to book ratio of equity, and is closest in size to the disruption experiencing firm (size matched benchmark)
- 6.81% relative to the firm that has similar size and market to book ratio of equity, and is closest in terms of prior-performance to the disruption experiencing firm (performance matched benchmark).
- 7.81% relative to the firm that has similar size, prior performance, and market to book ratio of equity, and is closest in terms of the industry to the disruption experiencing firm industry matched benchmark).

When one examines the relative stock price performance during the time periods before and after the disruption announcement, the shareholder value effects are much worse than those depicted in Figure 1. Figure 2 depicts the stock price performance starting one year before and ending two years after the disruption announcement date. The stock price performance is measured relative to the portfolio of all firms that have similar prior-performance, size, and market to book ratio of equity to the disruption experiencing firm.

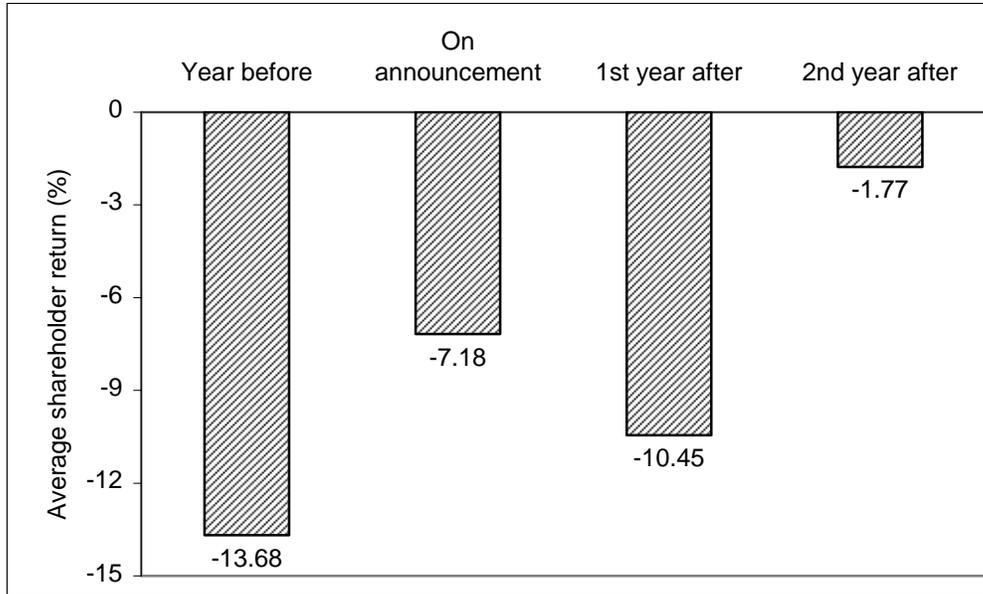


Figure 2: The average shareholder returns during the year before the disruption announcement, on announcement, and each of the two years after the disruption announcement. The shareholder returns are estimated relative to the portfolio of all firms that have similar prior-performance, size, and market to book ratio of equity to the disruption experiencing firm.

During the year before the disruption announcement, stocks of disruption experiencing firms underperformed their benchmark portfolio by nearly 14%. Even after the announcement of disruptions, firms continue to experience worsening stock price performance. In the year after the disruption announcement firms on average lose another 10.45% relative to their benchmark portfolios. Although the negative trend continues in the second year after disruption, the magnitude of underperformance of 1.77% is not as high as that during the year before and the first year after the disruption announcement. More importantly, the results show that firms do not recover during this time period from the negative stock price performance that they experienced in the prior two years, indicating that the loss associated with disruptions is not a short term effect.

Figure 3 depicts the extent of shareholder value loss associated with disruptions over the three year period. Depending on the benchmark used the average level of underperformance on

shareholder returns ranges from 33% to 40%. One way to judge the economic significance of this level of underperformance is the fact that on average stocks have gained 12% annually in the last two decades. Even if a firm experiences one major supply chain disruption every 10 years, the annual return would be close to 8-9%, which is a significant difference when one takes into account the effect compounding over long-time period. Clearly, it pays to avoid supply chain disruptions. These results also underscore the importance of why senior executives must be aware of and actively involved in monitoring and managing the performance of their firm's supply chain.

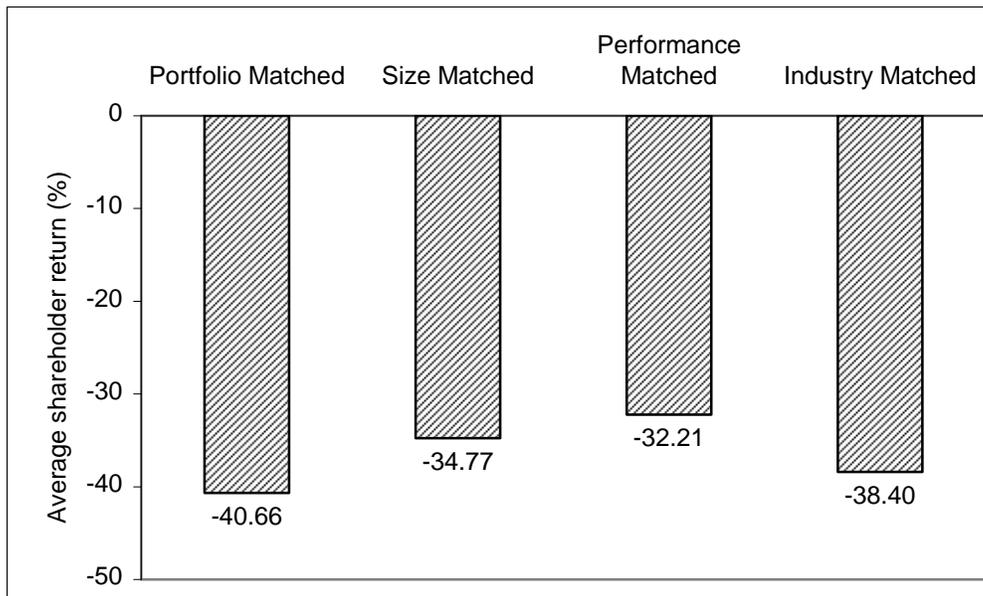


Figure 3: The average shareholder returns relative to various benchmarks measured over a three year period that begins a year before the disruption announcement and ends two years after the disruption announcement. Portfolio, size, performance, and industry matched are different set of benchmarks used to estimate the relative stock price performance of the firms that experience disruptions.

The average level of share price underperformance documented in Figure 3 is not driven by a few outliers or special cases. Figure 4 shows that anywhere from 62% to 68% of the firms that experience disruption underperform their respective benchmarks over a three year period, which is a statistically significant level of underperformance.

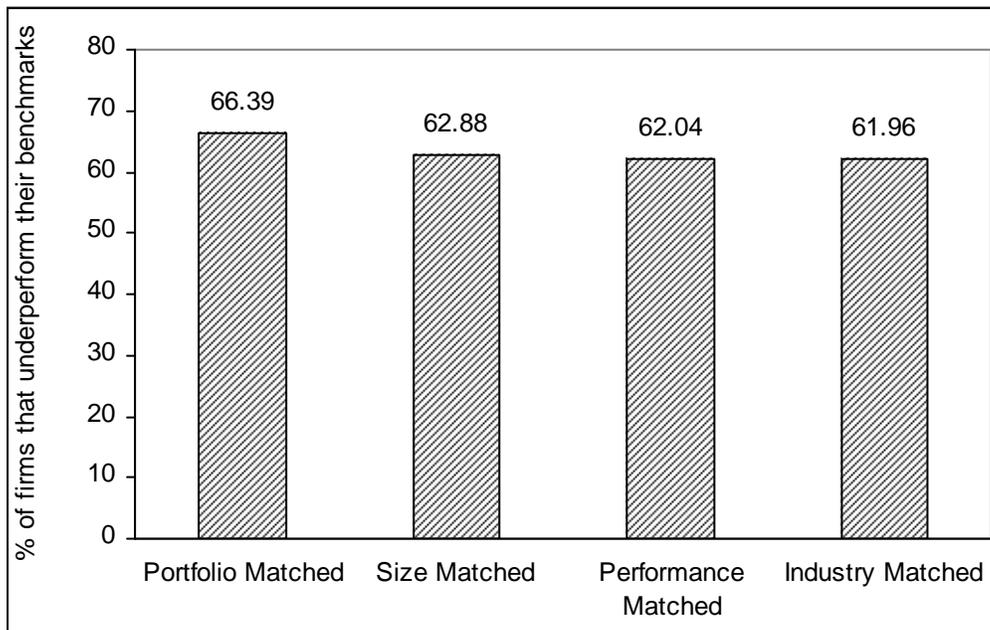


Figure 4: The percent of disruption experiencing firms that underperform their benchmarks over a three year period that begins a year before the disruption announcement and ends two years after the disruption announcement. Portfolio, size, performance, and industry matched are different set of benchmarks used to estimate the relative stock price performance of the firms that experience disruptions.

In summary, Figures 1 through 4 indicate the following:

- Supply chain disruptions result in significant short-term and long-term shareholder value losses. 33 to 40% stock price underperformance over three years is both economically and statistically significant.
- Firms that experience disruptions do not recover quickly from the stock price underperformance. Disruptions have a long-term devastating effect on shareholder value.

VI. The effect of supply chain disruptions on profitability

The magnitude of stock price underperformance associated with supply chain disruptions and the lack of any recovery may surprise many and could raise the issue whether the significant stock price underperformance is supported by corresponding reduction in profitability or is it simply a matter of stock market overreaction. This issue is explored by documenting the long-term effects of disruptions on operating income, sales growth, cost growth, as well as changes in the level of assets and inventories. As in the case of the analysis of stock price performance, profitability effects are estimated starting one year before and ending two years after the disruption announcement.

The key results of this analysis are highlighted in Figures 5 through 13. To control for industry, economy, and others affects the performance of the disruption experienced firms is compared to controls using the three different control samples described in Appendix III. Since the three control samples give similar results, the results from the control sample where most of the sample firms are matched are reported. Since accounting data are more prone to extreme values or outliers, the average values reported are those obtained after trimming 1% on each tail. The median changes, which are less influenced by outliers, are also reported.

Results for the year before the disruption announcement

Figures 5 through 7 present the results for the time period that begins four quarters before the disruption announcement and ends during the quarter of the disruption announcement. The results indicate that supply chain disruptions have a devastating effect on profitability. Figure 5 shows that firms that experience disruptions on average experience a 107% decrease operating income, 114% decrease in return on sales, and 92% decrease in return on assets. Outliers are not

driving the negative mean changes in operating-income based measures. The median of the percent changes in operating income, return on sales, and return on assets are -42%, -32%, and -35%, respectively.

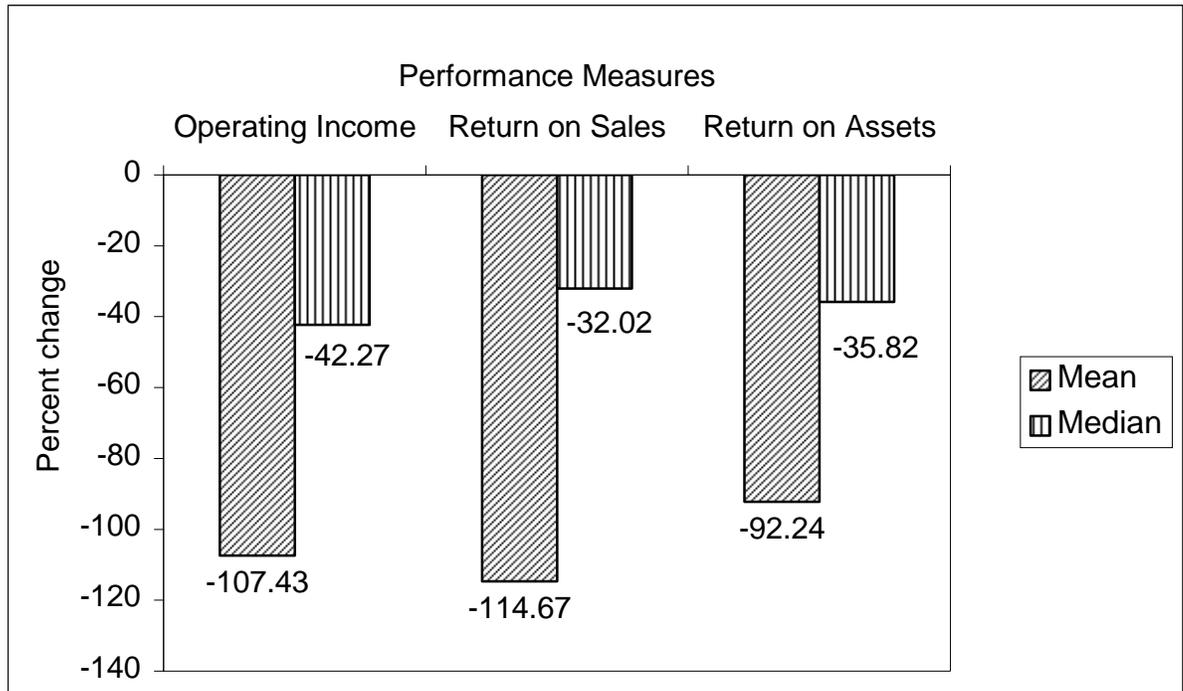


Figure 5: Control-adjusted changes in profitability related measures from supply chain disruptions during the year before the disruption announcement. Results are reported for the time period that begins four quarters before the disruption announcement and ends during the quarter of the disruption announcement.

The proportion of firms experiencing negative performance (see Figure 6) indicates that disruptions are bad news across the board. For example, nearly 67 to 69% of the sample firms experienced a negative change in operating income.

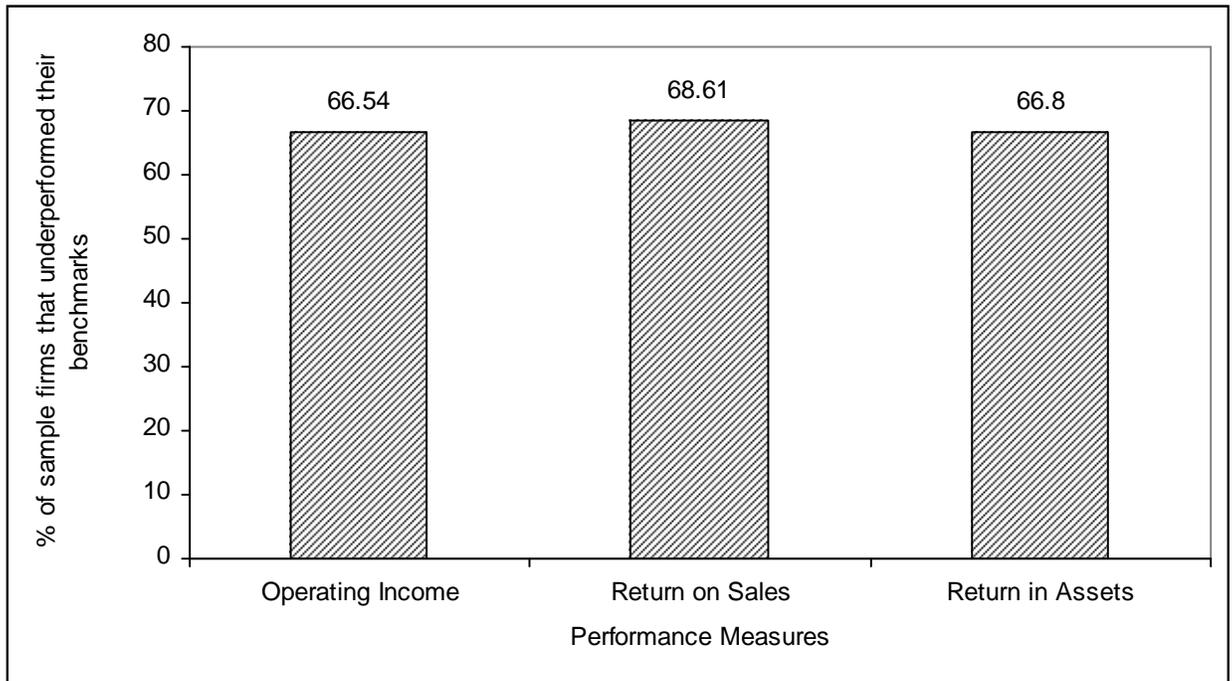


Figure 6: The percent of disruption experiencing firms that underperform their benchmarks during the year before the disruption announcement. Results are reported for the time period that begins four quarters before the disruption announcement and ends during the quarter of the disruption announcement.

Figure 7 indicates that supply chain disruptions negatively affect sales. The mean (median) percent change in sales is about -7% (-3%). Nearly 54% of the sample firms experienced negative sales growth. Disruptions also increase total costs. The mean (median) change in total costs is about 11% (4%). Nearly 65% of the sample firms experience an increase in total costs. The drop in sales together with the increase in total costs explains the economically significant drop in operating income-based measures of Figure 5.

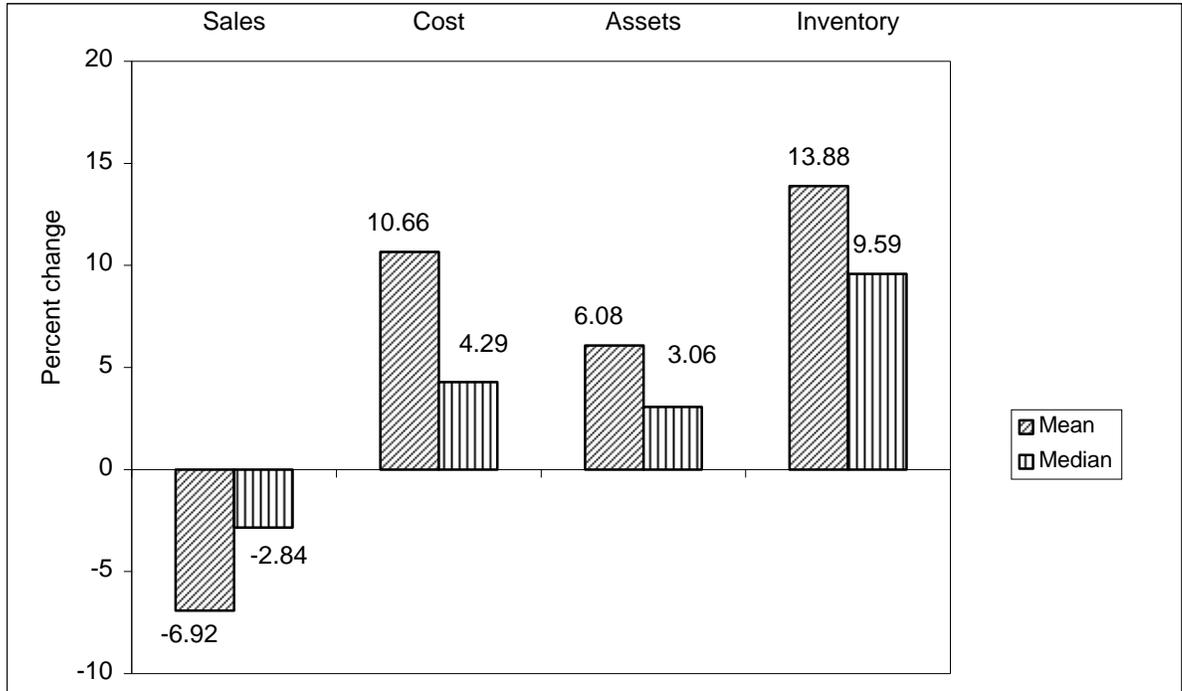


Figure 7: Control-adjusted changes in sales, costs, assets, and inventories of firms experiencing supply chain disruptions during the year before the disruption announcement. Results are reported for the time period that begins four quarters before the disruption announcement and ends during the quarter of the disruption announcement.

Disruptions also cause a significant increase in total assets. The mean (median) change in total assets is about 6% (3%). Normally, an increase in the asset base can be considered positive as it indicates positive growth. But in the case of supply chain disruptions it is bad news as it indicates lower asset turnover since assets are increasing while sales are decreasing. Firms experiencing disruptions show an increase in total inventories. The mean (median) change in the total inventory levels is about 14% (10%). Nearly 59% of the sample firms experienced an increase in their inventory. Again this is bad news as inventories are increasing while sales are decreasing.

Results for the first year after the disruption announcement

Figures 8 through 10 present the results for the first year after the disruption announcement (the time period that begins during the quarter of the disruption announcement and ends four quarters after the disruption announcement). These results provide insights into any persistence of the negative effect of disruption on performance, and the extent and speed of recovery, if any, from disruptions. Figure 8 indicates that subsequent to the disruption announcement, there is some evidence of further weakness of performance. However, the magnitude of deterioration of performance is much less than those reported during the year leading to the disruption announcement (see Figure 5).

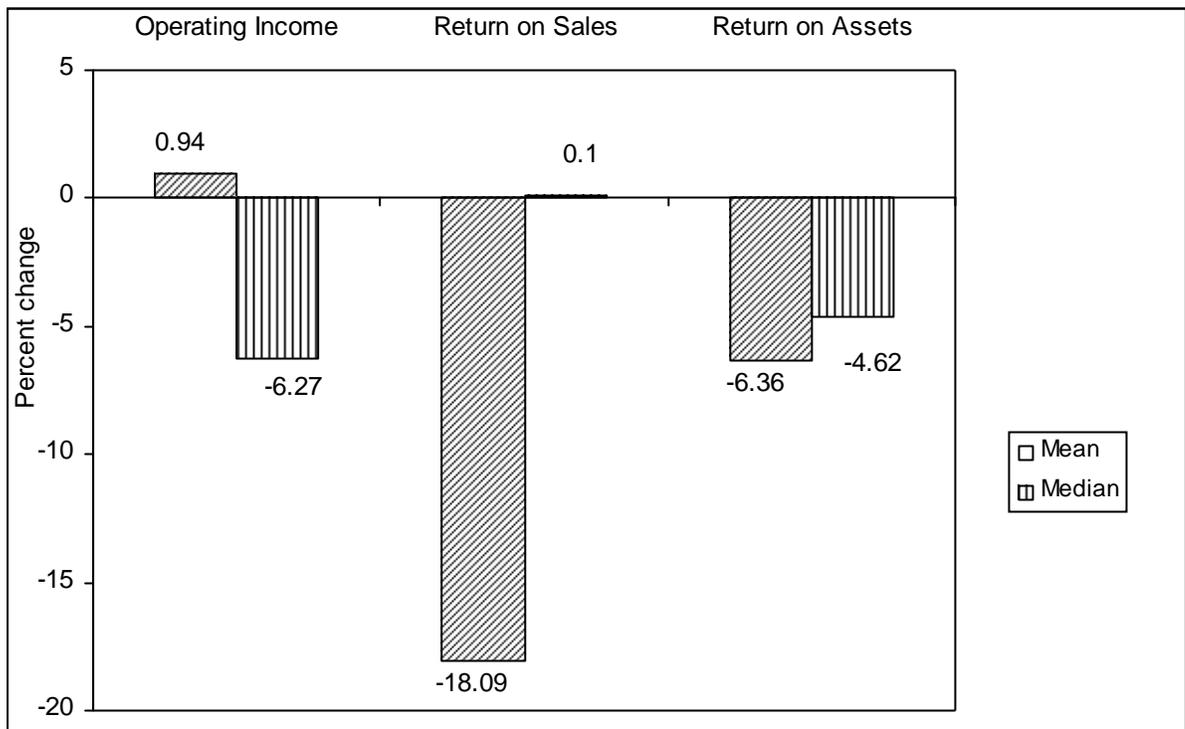


Figure 8: Control-adjusted changes in profitability related measures of firms experiencing supply chain disruptions during the first year after the disruption announcement. Results are reported for the time period that begins during the quarter of the disruption announcement and ends four quarters after the disruption announcement.

Figure 9 indicates that percent of disruption experiencing firms that under-perform their benchmarks is close to 50%.

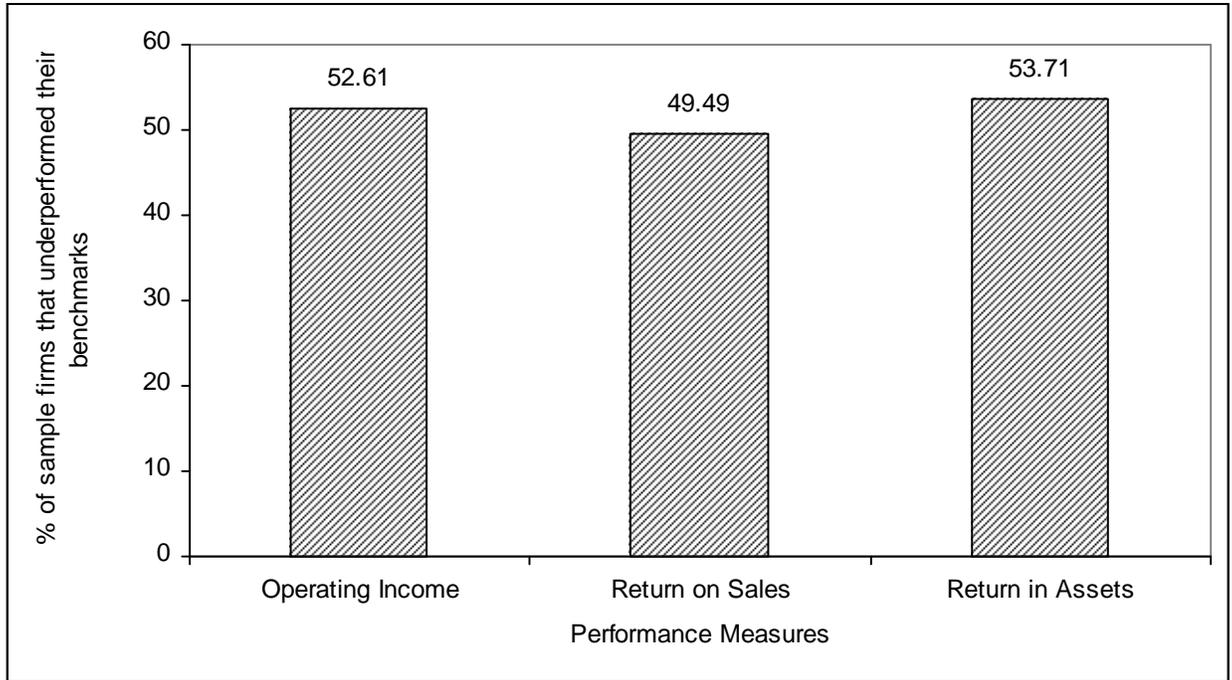


Figure 9: The percent of disruption experiencing firms that underperform their benchmarks during the first year after the disruption announcement. Results are reported for the time period that begins during the quarter of the disruption announcement and ends four quarters after the disruption announcement.

Figure 10 shows that the negative trends in sales, cost, assets and inventories continue but the magnitude of changes are not as dramatic as that observed during the year leading to the disruptions.

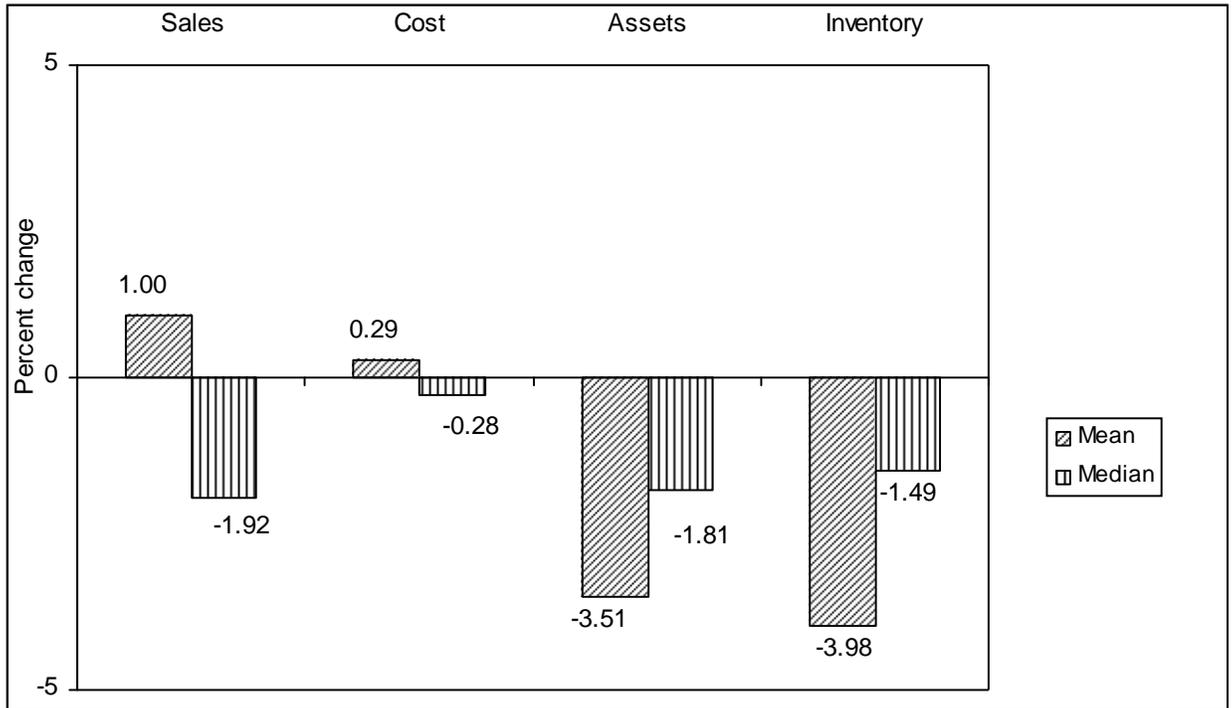


Figure 10: Control-adjusted changes in sales, costs, assets, and inventories of firms experiencing supply chain disruptions during the first year after the disruption announcement. Results are reported for the time period that begins during the quarter of the disruption announcement and ends four quarters after the disruption announcement

Results for the second year after the disruption announcement

Figures 11 through 13 present the results for the time period that begins four quarters after and ends eight quarters after the disruption announcement. Figure 11 indicates that in the second year after the disruption announcement, there is further weakness of performance as evidenced by the negative changes in profitability measures. However, the magnitude of deterioration of performance is much less than those reported during the year leading to the disruption announcement (see Figure 5).

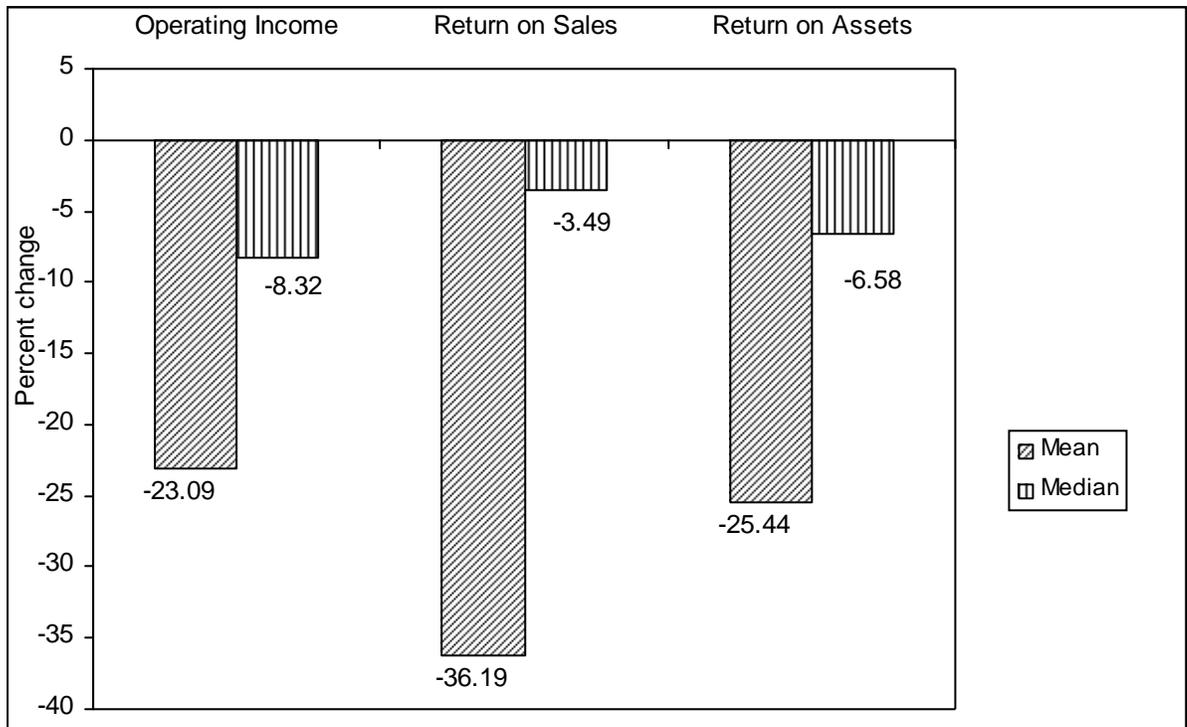


Figure 11: Control-adjusted changes in profitability related measures of firms experiencing supply chain disruptions during the second year after the disruption announcement. Results are reported for the time period that begins four quarters after and ends eight quarters after the disruption announcement.

Figure 12 indicates that percent of disruption experiencing firms that under-perform their benchmarks is about 52%.

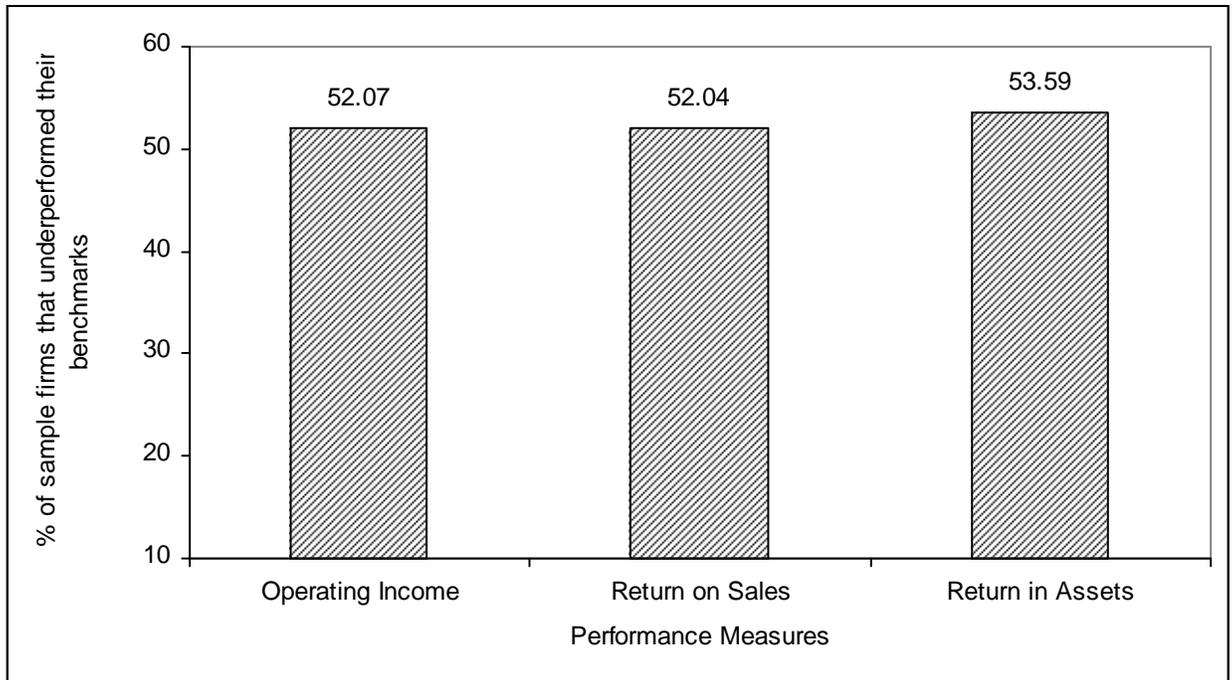


Figure 12: The percent of disruption experiencing firms that underperform their benchmarks during the second year after the disruption announcement. Results are reported for the time period that begins four quarters after and ends eight quarters after the disruption announcement.

Figure 13 shows that the negative trends in sales, cost, assets, and inventories continues but the magnitude of changes are not as dramatic as that observed during the year leading to the disruptions. There is some weak evidence to suggest that during this time period disruption experiencing firms were able to reduce assets and inventories, probably an indicating of restructuring.

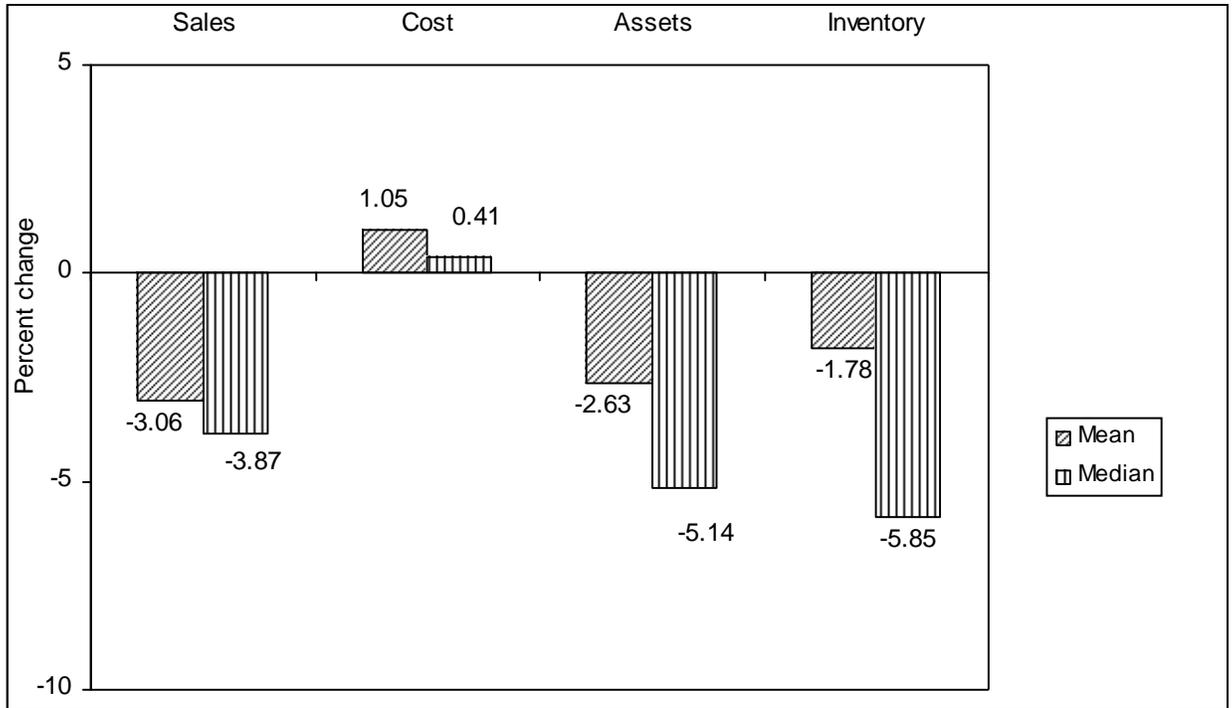


Figure 13: Control-adjusted changes in sales, costs, assets, and inventories of firms experiencing supply chain disruptions during the second year after the disruption announcement. Results are reported for the time period that begins four quarters after and ends eight quarters after the disruption announcement

The results of Figures 5 through 13 indicate that

- Supply chain disruptions have an economically significant negative effect on operating performance. Disruptions cause steep drop in profitability, reduce sales growth rate, increase cost of manufacturing and selling products as well as increase assets and inventories.
- Firms that experience disruptions do not recover quickly from the negative effect of disruptions. Firms start at a higher level of operating performance before disruptions, disruptions lowers the level of operating performance, and firms continue to operate at a lower level for at least the next couple of years.

- The results on operating performance are consistent with the results on shareholder value. The reason that stock market penalizes firms for supply chain disruption is because disruptions lead to lower profitability and growth rates, two factors that are key drivers of shareholder value.

VII. The effect of supply chain disruptions on share price volatility

Supply chain disruptions can create uncertainty about a firm's future prospects and can raise concerns about its management capability as disruptions indicate management inability to manage and control crucial business processes. Disruptions may also lead to questions and concerns about a firm's business strategy. Disruptions could therefore increase the overall risk of the firm. Understanding how disruptions can affect the risk of the firm is important for a number of reasons:

- Risk is a critical factor used by investors to value a firm's securities. Risk influences the return that investors demand for holding securities and hence directly affects the pricing of securities.
- The discount rate used in capital budgeting is directly related to the risk of the firm. Furthermore, the cost of capital when raising capital via equity and/or debt is influenced by the risk of the firm. The higher the risk, the higher is the cost of capital.
- Increased risk can make the firm's shares a less attractive currency for acquisitions as potential targets may be less willing to do deals that depends on volatile share prices.

- Rating agencies such as Moody' and S&P 500 consider the risk of the firm in determining a firm's credit rating. Increase in risks can result in downgrading of debt by credit rating agencies, making it more expensive and difficult to raise capital. It can also increase the probability of financial distress as the chances of the firm not being able to cover its fixed commitments increases as the risk increases.
- Risk changes can also create conflicts between the various stakeholders. An increase in share price volatility transfers wealth from bondholders to shareholders, a potential source of conflict that may require management time and attention. Risk-averse employees may demand higher compensation to work for a firm that has high risk. Suppliers and customers may also be wary of dealing with the firm that has high risk and may demand some form of assurances and guarantees before doing business with the firm, thereby raising the cost of doing business for the firm.

To estimate the effect of disruptions on risk, this study compared the share price volatility before and after the disruption announcement date. Share price volatility is measured by the standard deviations of stock returns, which are estimated annually for four years, starting two years before through two years after the disruption announcement. To control for other factors that could affect volatility, percent changes in the standard deviation of stock returns of the disruption experiencing firms are compared against that of a matched control sample.

Figure 14 gives share price volatility (standard deviation of stock returns) using daily stock returns for the firms that experienced supply chain disruptions. The figure indicates that the share price volatility is monotonically increasing starting two year before the disruption

announcement and ending two years after the disruption. For example, the standard deviation of stock returns in the second year before the disruption announcement was 4.13% and since then has steadily increased to 5.05% in the second year after the disruption announcement. The evidence supports the view that disruptions increase the share price volatility, and hence the risk of the firm.

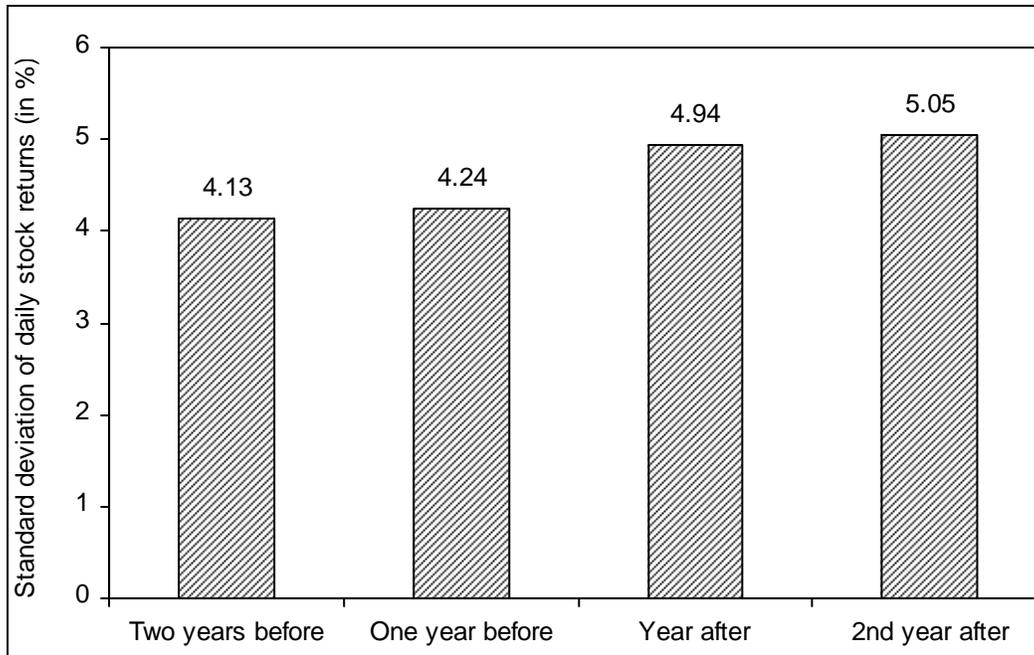


Figure 14: Estimated standard deviation of stock returns over a four year time period for the sample of firms that experienced disruptions.

A better idea of the extent of share price volatility can be had by comparing the change in the share price volatility of disruption experiencing firms against the change in share price volatility experienced by a control sample. Table 15 reports these results. The results indicate that after adjusting for other factors that could affect share price volatility there is still a significant increase in volatility that can be attributed to the disruption. Much of this increase happens after the disruption announcement. For example, the share price volatility increases by 13.5% in the year after the disruption when compared to the volatility one year before the

disruption announcement. Furthermore, the share price volatility remains at this high level for at least the next year or two. Overall, disruptions increase the risk of the firm.

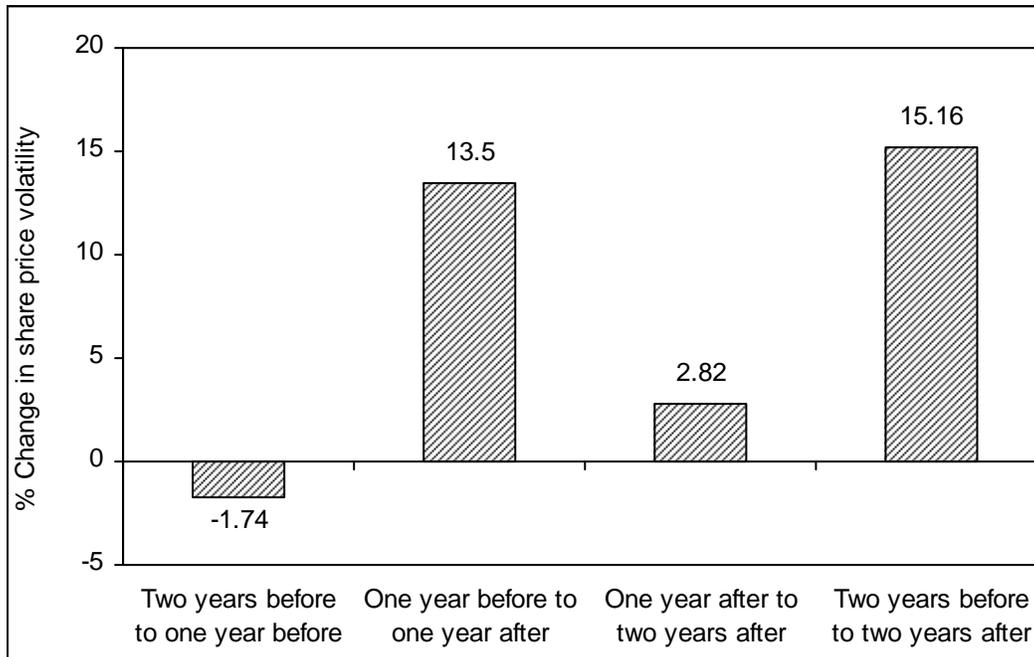


Figure 15: Estimated percent changes in standard deviation of stock returns over a four year time period. The reported percent changes are the difference between the percent changes of the disruption experiencing firms and its control firms.

VIII. The effect of supply chain disruptions by industry

To provide more details about the effect of supply chain disruptions on different firms, the results for the full sample of disruptions were segmented in a number of different ways. One set of analyses explored how the effect of disruptions varies by industry. Seven broad industry groups were defined and sample firms were assigned to these groups based on their primary SIC codes. Figures 16 and 17 illustrate the effect of disruptions on performance for four of these seven industry groups, as the remaining three had sample sizes less than 40. These four industry groups are:

- Process industry - primary SIC code between 2000-2999 (food, tobacco,

textiles, lumber, wood, furniture, paper, and chemicals).

- High Technology industry - primary SIC code between 3570-3579, 3660-3699 or 3760-3789 (computers, electronics, communications, defense).
- Wholesale and retail industry - primary SIC code between 5000-5999 (wholesaling, retailing).
- Service industry - primary SIC between 6000-6999 (services, financial services, government).

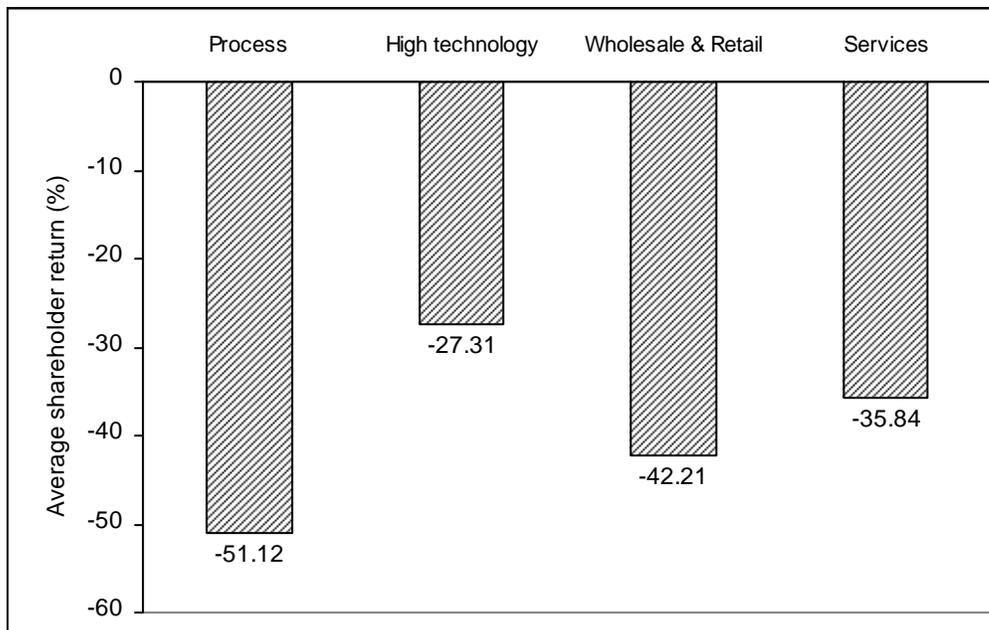


Figure 16: The average shareholder return relative to the benchmark that consists of the portfolio of all firms that have similar prior-performance, size, and market to book ratio of equity to the disruption experiencing firm. Results for the four industry groups are reported over a three year period that begins a year before the disruption announcement and ends two years after the disruption announcement.

Figures 16 and 17 indicate that disruptions have a negative effect on all measures of performance across all industry groups. The following can be observed:

- The average level of stock price underperformance was -51% for firms in the process industry, -27% for firms in the high technology industry, -42% in the case

of the wholesale and retailing, and -36% in the case of service industry.

- The median changes in operating income for all industry groups are negative, with nearly -55% for the process industry, -57% for the high technology industry group, -5.5% for the wholesale and retail sector, and -70% for the service sector.
- Except for the wholesale and retail industry, all other industry groups show a significant decrease in the median percent change in sale.
- All industry groups show a statistically significant increase in total costs.

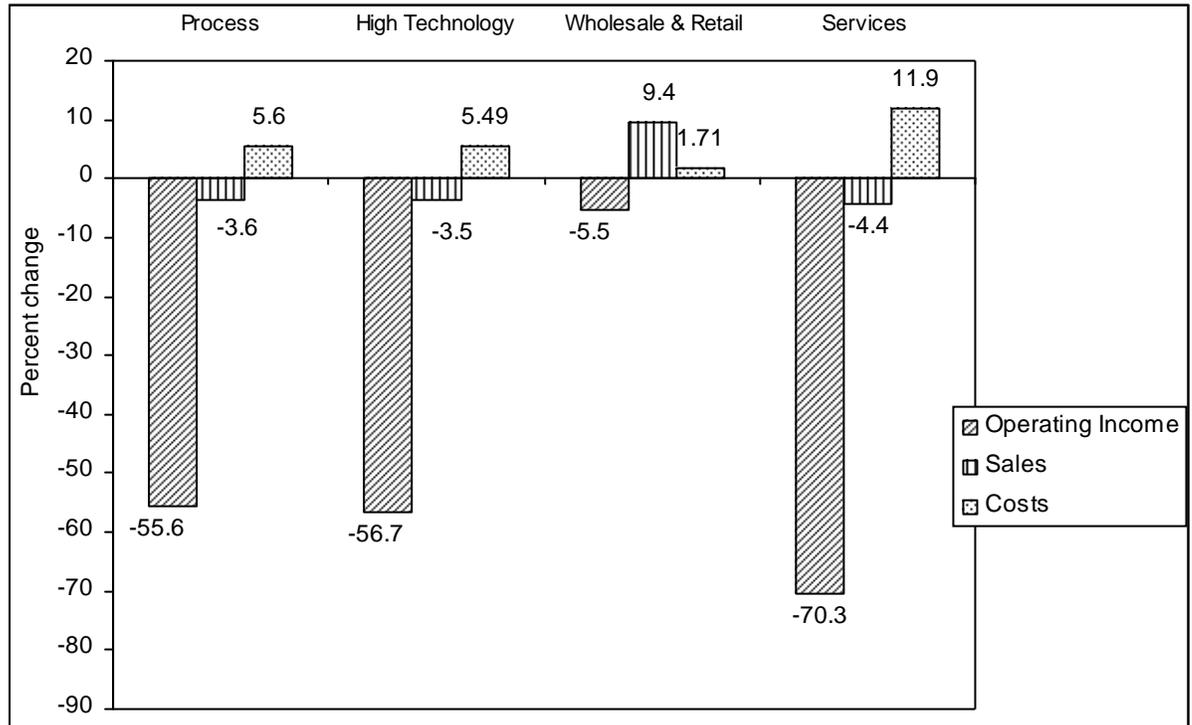


Figure 17: Control-adjusted median changes in profitability related measures. Results for the four industry groups are reported for the time period that begins four quarters before the disruption announcement and ends during the quarter of the disruption announcement.

Note that Figure 17 and all other subsequent figures that report profitability measures report the median effect of disruptions across different subsamples. The reason for reporting

median values instead of mean values is that outliers do not influence median values as much as they influence mean values. Furthermore, outliers can significantly distort mean values when sample sizes are small, which is indeed the case when the full sample of disruptions is segmented into different subsamples.

It is clear from Figures 16 and 17 that it does not matter which industry a firm belongs to – supply chain disruptions have an across-the-board negative effect on shareholder value and profitability. No industry is immune from the devastating effect of disruptions on performance. This is important because much of the current discussions about supply chain management seem to be focused on the high technology industry. While supply chain issues are certainly critical for the high technology industry, they are no less important for other and more mature industries.

IX. Supply chain disruptions and firm size

Figures 18 and 19 indicate that the effect of supply chain disruptions on shareholder value and profitability depends on firm size. In particular, the effect of disruptions is more pronounced for smaller firms when compared to larger firms. More specifically:

- In terms of shareholder returns, the level of underperformance is more severe for smaller firms than larger firms. For the three size quintiles (quintiles 1 through 3) that represent smaller firms, the level of underperformance ranges from 47% to 64%. In contrast for the quintiles that represent larger firms (quintiles 4 and 5), the level of underperformance ranges from about 20% to 32%.
- The accounting metrics also indicate that profitability drops are more severe for smaller firms when compared to larger firms. Smaller firms experience a median change in operating income of about -87%, return on sales of -72% and

return on assets of -66% compared to -30%, -25%, and -23% for the larger firms.

In reporting these results, firms below (above) the median asset value of the sample are classified as smaller (larger firms).

- Compared to larger firms, smaller firms show a larger decline in revenue (-7.8% vs. 0.3%) and larger increase in costs (7.6% vs. 2.6%).

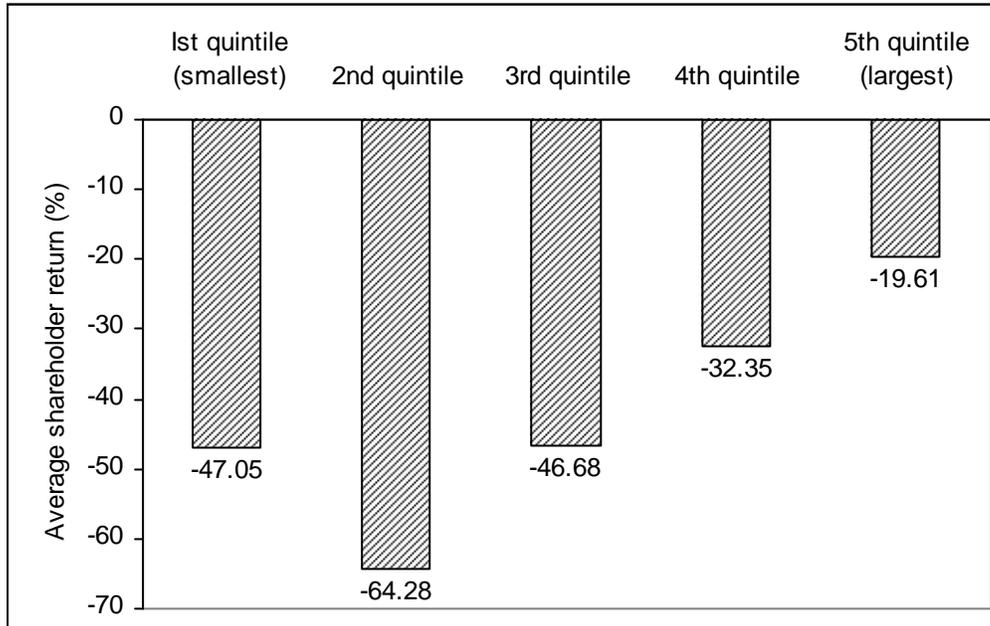


Figure 18: The average shareholder return relative to the benchmark that consists of the portfolio of all firms that have similar prior-performance, size, and market to book ratio of equity to the disruption experiencing firm. Results for the various size quintiles are reported over a three year period that begins a year before the disruption announcement and ends two years after the disruption announcement.

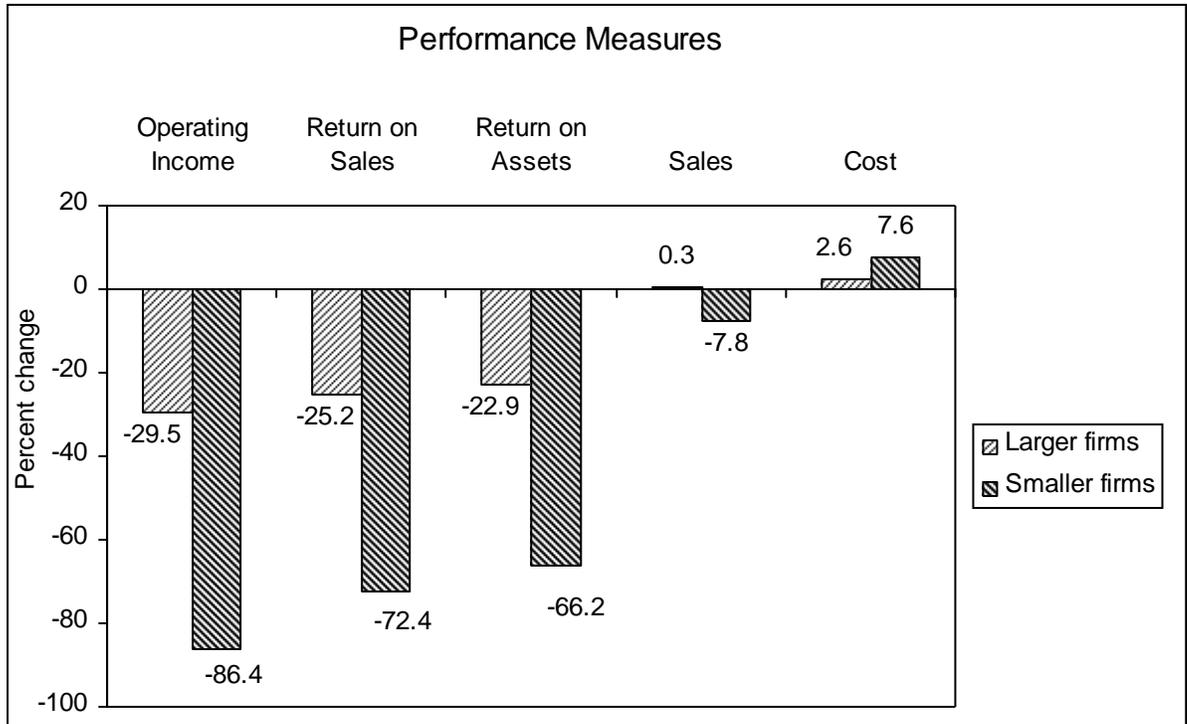


Figure 19: Control-adjusted median changes in profitability related measures. Results for smaller and larger firms are reported for the time period that begins four quarters before the disruption announcement and ends during the quarter of the disruption announcement.

The more severe effect of supply chain disruptions for smaller firms could be because smaller firms are more likely to be highly focused and hence, their profitability is dependent on the flawless execution of the supply chains for their limited set of products. Smaller firms may take longer to recover from disruptions as their small size reduces their power and clout to influence and change the behavior of other supply chain partners to speed recovery.

X. The effect of supply chain disruptions by responsibility for disruptions

Figure 20 indicates that a number of different sources were responsible for supply chain disruptions. In about 34% of the cases used in this study, the primary responsibility was attributed to internal sources – that is, the firm took responsibility for the disruptions. In nearly

15% of the cases, suppliers were the primary source of the problem. Customers were responsible in 13% of the cases, nature and government were responsible in about 4% of the cases, and various other combinations of responsible parties accounted for 6% of the cases. About 29% of the cases did not have sufficient information to assign the source of responsibility.

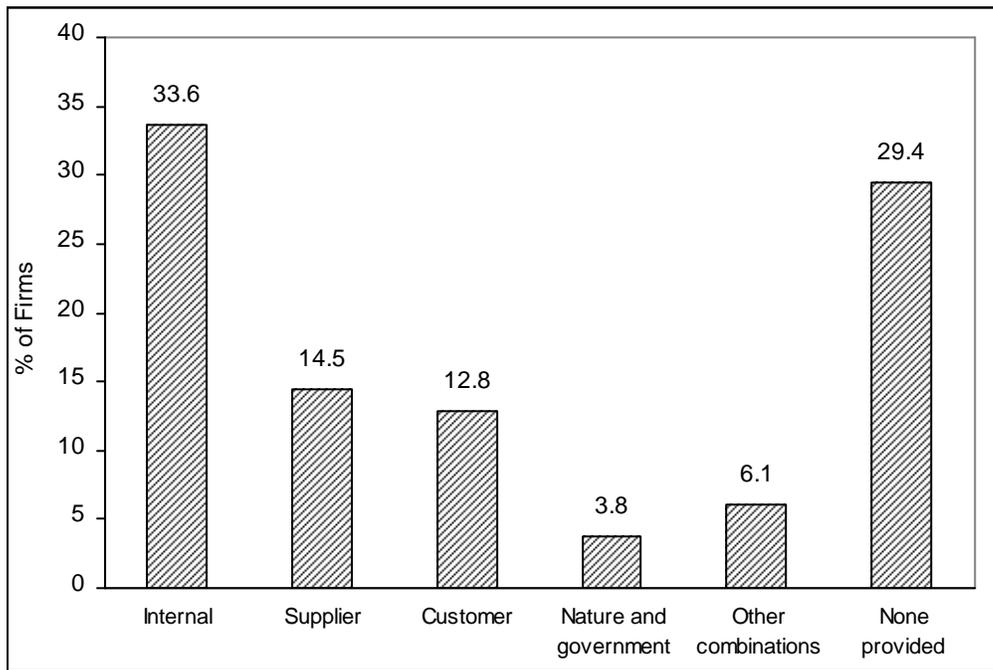


Figure 20: Distribution of the source of responsibility for the supply chain disruptions.

Figures 21 and 22 depict the performance effects for internal, supplier, and customer caused disruptions. The key results are:

- Over the three period that begins one year before and ends two years after the disruption announcement, stock prices of firms that experienced internally caused disruptions underperformed their benchmarks by an average of 35.69%, by 24.93% for supplier caused disruptions, and 52.88% in the case of disruptions caused by customers.

- Internal disruptions are associated with a median decrease in operating income of 43.7%, a decrease in sales of 4.3%, and an increase in costs of 4.5%.
- Disruptions due to supplier result in median decrease in operating income of 29.9%, a decrease in sales of 1.1%, and an increase in costs of 1.3%.
- Customer caused disruptions are associated with a median decrease in operating income of 55.02%, a decrease in sales of 5.6%, and an increase in costs of 5.8%.

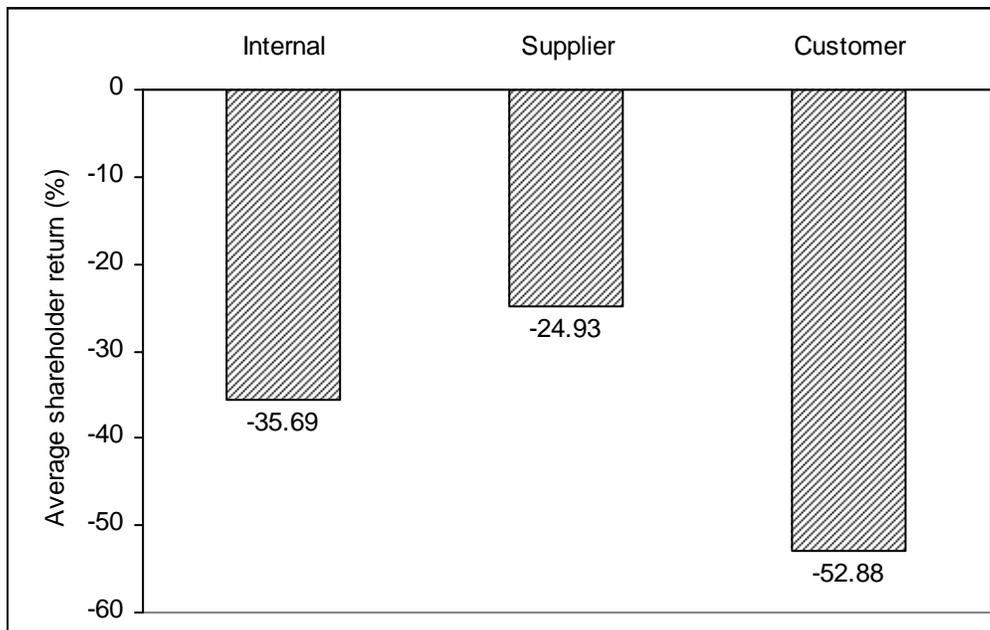


Figure 21: The average shareholder return relative to the benchmark that consists of the portfolio of all firms that have similar prior-performance, size, and market to book ratio of equity to the disruption experiencing firm. Results for the various sources of responsibility are reported over a three year period that begins a year before the disruption announcement and ends two years after the disruption announcement.

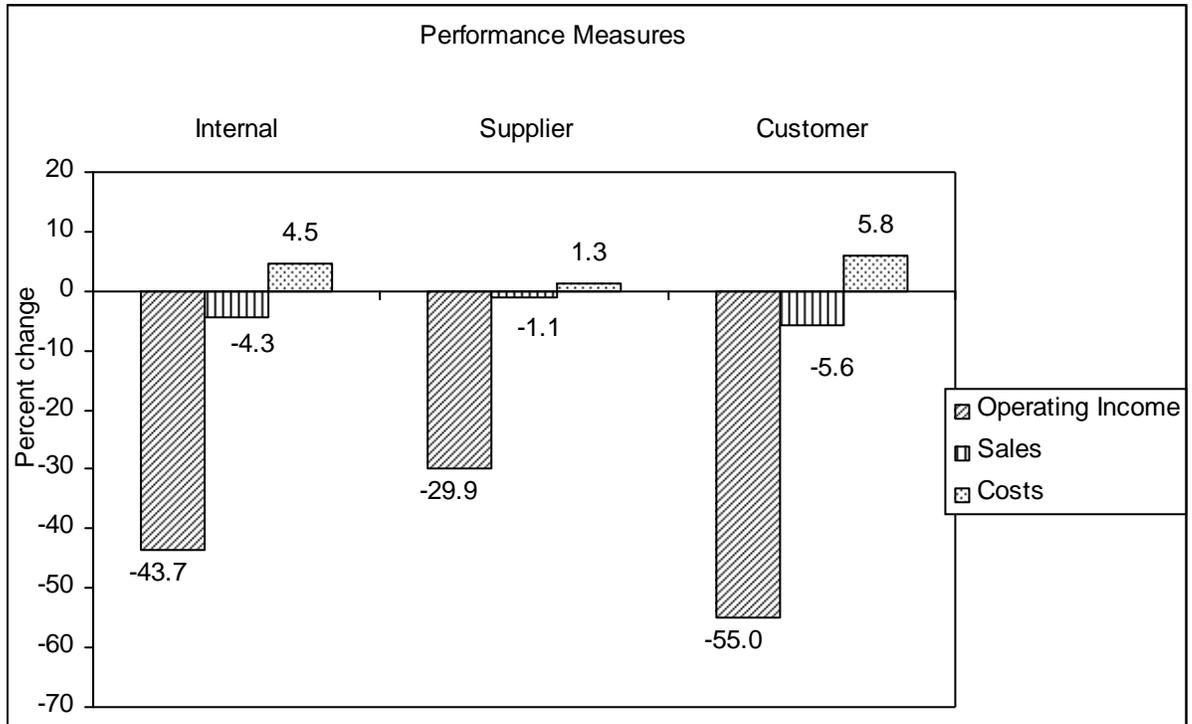


Figure 22: Control-adjusted changes in profitability related measures. Results for various sources of responsibility are reported for the time period that begins four quarters before the disruption announcement and ends during the quarter of the disruption announcement.

The basic observation from Figures 21 and 22 is that shareholder value and operating performance effects are negative irrespective of which link in the supply chain is responsible for the disruption. The results show the heavy price one link in the supply chain pays for the poor performance by other links in the supply chains. Such significant losses should provide an incentive for various links in the supply chain to collaborate and co-operate to minimize disruptions in supply chains. The fact that disruptions caused by external sources (suppliers and customers) are also severely penalized highlights the importance to firms of effective supplier relationship management and customer relationship management to increase the efficiency, reliability, and responsiveness of their supply chains.

XI. The effect of supply chain disruptions by reasons for disruptions

Figure 23 indicates the primary reasons cited for the supply chain disruptions. In about 22% of part shortages were the primary reasons for disruptions. Ramp/roll-out problems, order changes by customers, and various production problems each resulted in disruptions in 9% of the cases. Development problems were cited in 4% of the cases and quality problems in about 3% of the cases. About 29% of the cases did not have sufficient information to determine the reason for disruption.

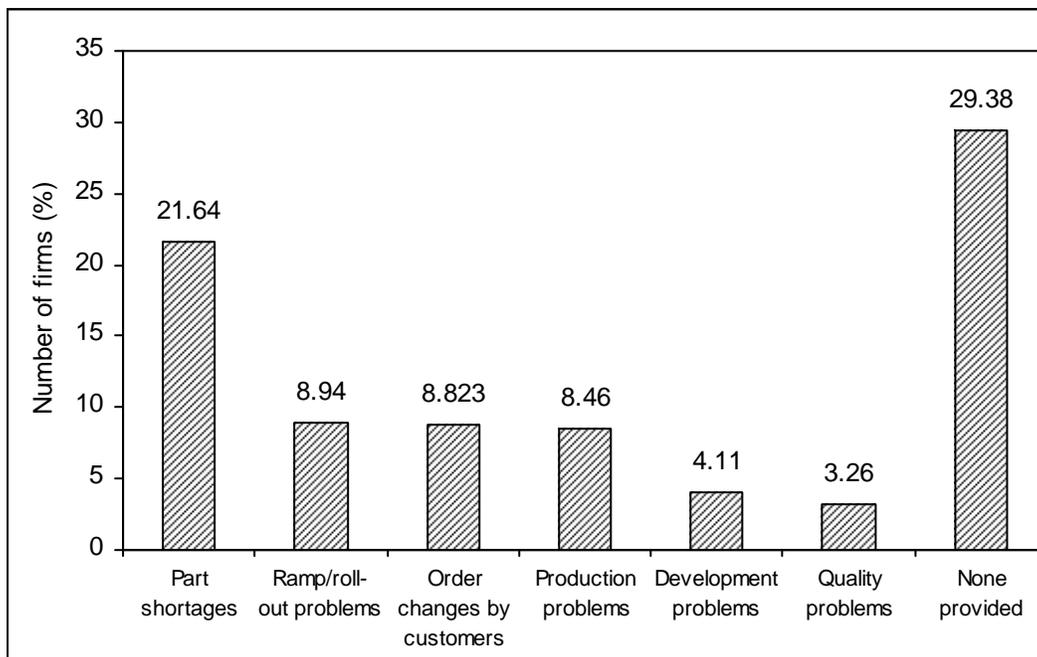


Figure 23: Distribution of primary reasons for the supply chain disruptions

Figures 24 and 25 depict the performance effects for the top four reasons for disruptions. The key results are:

- Stock prices of firms that experienced disruptions due to parts shortages underperformed their benchmarks by an average of 25.48%. Parts shortages are associated with a median decrease in operating income of 31.2%, a decrease in

sales of 1.2%, and an increase in costs of 1.7%. Poor forecasting, poor planning, dependency on a single supplier, long lead times, and low inventory levels, among other things, can often cause part shortages. Although many have articulated the benefits of strategies such as single sourcing and low inventory levels, it is not clear if there is much awareness of how significant the cost can be if these strategies can cause severe parts shortages that disrupts the supply chain.

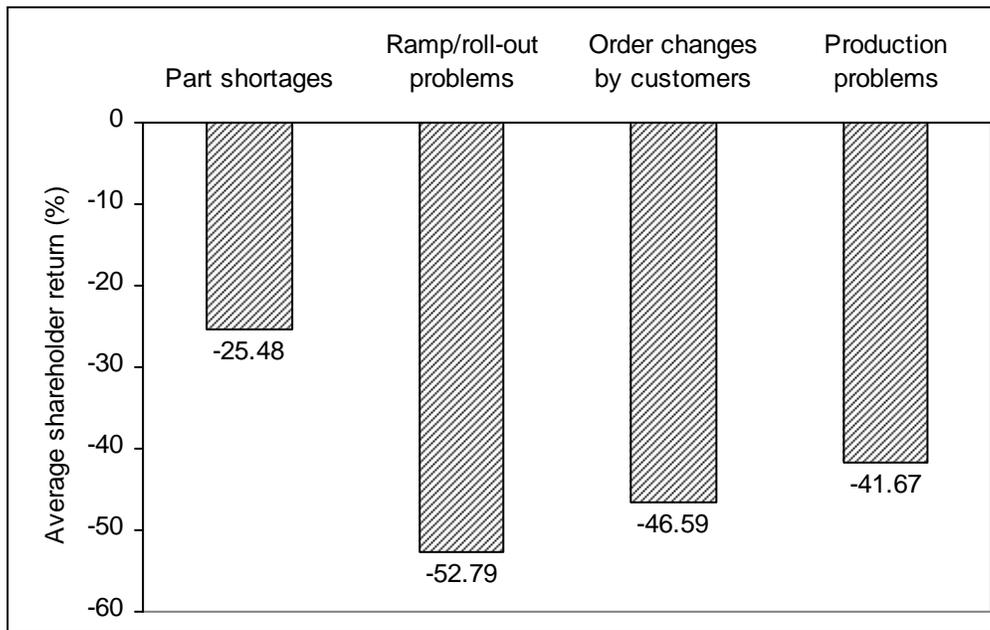


Figure 24: The average shareholder return relative to the benchmark that consists of the portfolio of all firms that have similar prior-performance, size, and market to book ratio of equity to the disruption experiencing firm. Results for the various reasons for disruptions are reported over a three year period that begins a year before the disruption announcement and end two years after the disruption announcement.

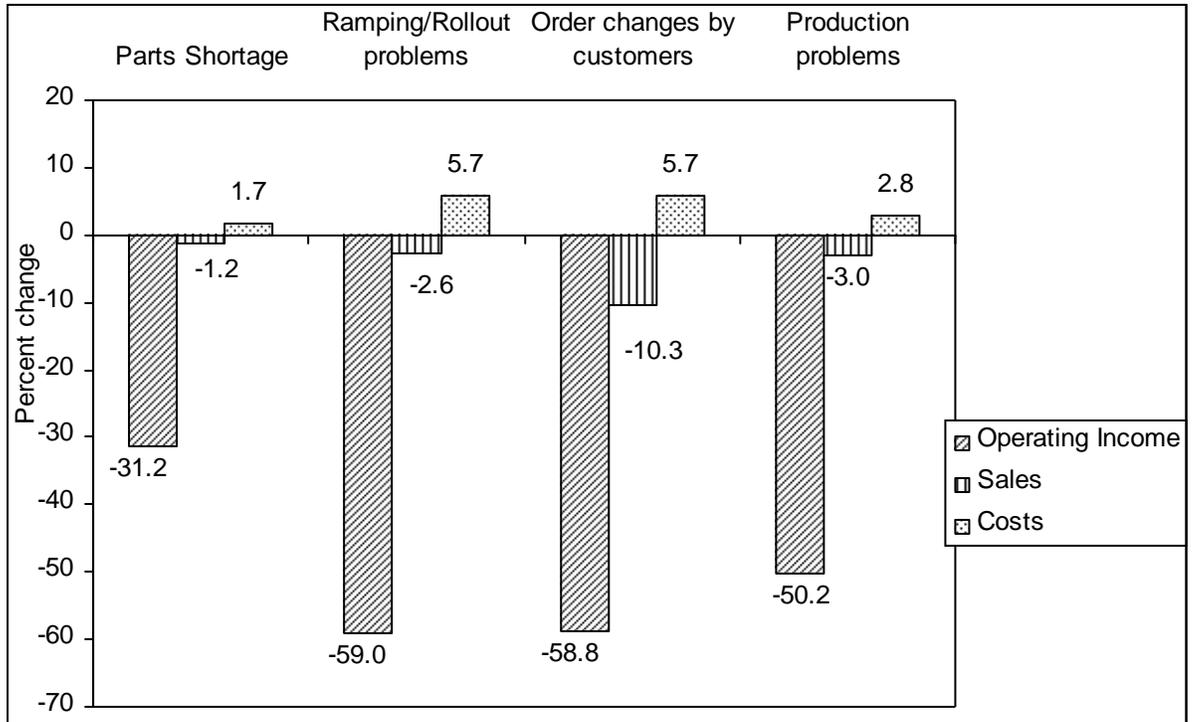


Figure 25: Control-adjusted changes in profitability related measures. Results are reported for the various reasons of disruptions for the time period that begins four quarters before the disruption announcement and ends during the quarter of the disruption announcement.

- The importance of rapid ramping and rollout of new products and processes is underscored by the fact that poor performance on these dimensions can have a significant negative effect on performance. Ramping and roll out problems results in stock price underperformance of 52.79%, with a median decrease in operating income of 59%, a decrease in sales of 2.6%, and an increase in costs of 5.7%.
- Order changes by customers devastate operating income. Last minute changes in customer needs are normal occurrences in today's environment where competition is intense, product life cycles are getting shorter, and product and process technologies are changing rapidly. Such disruptions are associated with

stock price underperformance of 46.59%, a decrease in operating income of 58.8%, a decrease in sales of 10.3%, and an increase in costs of 5.7%. This underscores the need for developing close relations with customers, with real-time visibility into their operations. It also highlights the need to develop more flexible and responsive supply chains, as well as the need to focus on enhancing forecasting, sales and operations planning, and master scheduling efforts to deal with customer driven changes.

- Disruptions due to production problems are associated with stock price underperformance of 41.67%, a decrease in operating income of 50.2%, a decrease in sales of 3%, and an increase in costs of 5.7%.

XII. Has the effect of disruptions on performance changed over time?

Given the recent emphasis on the criticality and importance of effective supply chain management for achieving competitive advantage, a natural question is whether the economically significant corporate performance effects documented above are due to the more recent supply chain disruptions. Figures 26, 27, and 28 shed some light on this issue. Figure 26 indicates that the number of disruptions that were publicly announced by firms during 1995-2000 have increased relative to those announced during 1989-1994. 69% of the disruptions announcements included in this study were made during 1995-2000 compared to only 31% during 1989-1994. The concentration of the announcements during 1995-2000 may be the result of the more exhaustive coverage by the databases of the more recent years. Alternatively, since supply chain performance issues are becoming more relevant in recent years, analysts and investors may be putting more pressure on firms to be more forthcoming about the performance

of their supply chains, particularly when it is poor.

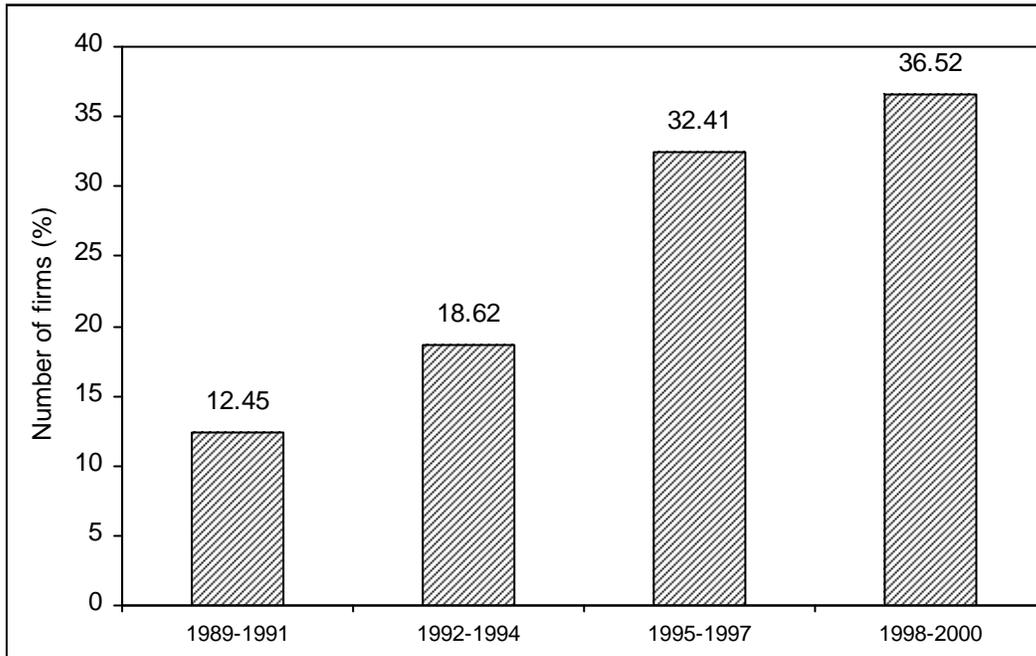


Figure 26: Distribution of supply chain disruptions over time.

Figure 27 reports the stock price performance by segmenting the 12-year time period into four non-overlapping time periods. Disruptions results in stock price underperformance in all four periods. During the earlier periods (1989-1991 and 1992-1994) the level of underperformance was about around 30%. More recent disruptions (1995-1997 and 1998-2000) are penalized more with an average underperformance of 51% during 1995-1997 and 37% during 1998-2000.



Figure 27: The average shareholder return relative to the benchmark that consists of the portfolio of all firms that have similar prior-performance, size, and market to book ratio of equity to the disruption experiencing firm. Results for the various time periods are reported for over a three year period that begins a year before the disruption announcement and ends two years after the disruption announcement.

Figure 28 reports the median profitability effects of earlier (1996 and before) and later (1997 and after) disruptions. The results suggest that the profitability effects for earlier disruptions are not that different from later disruptions. Disruptions are bad news irrespective of when they happen. While the current focus on improving supply chain reliability and responsiveness is timely and relevant, it is important to note that poor supply chain performance has always devastated corporate performance.

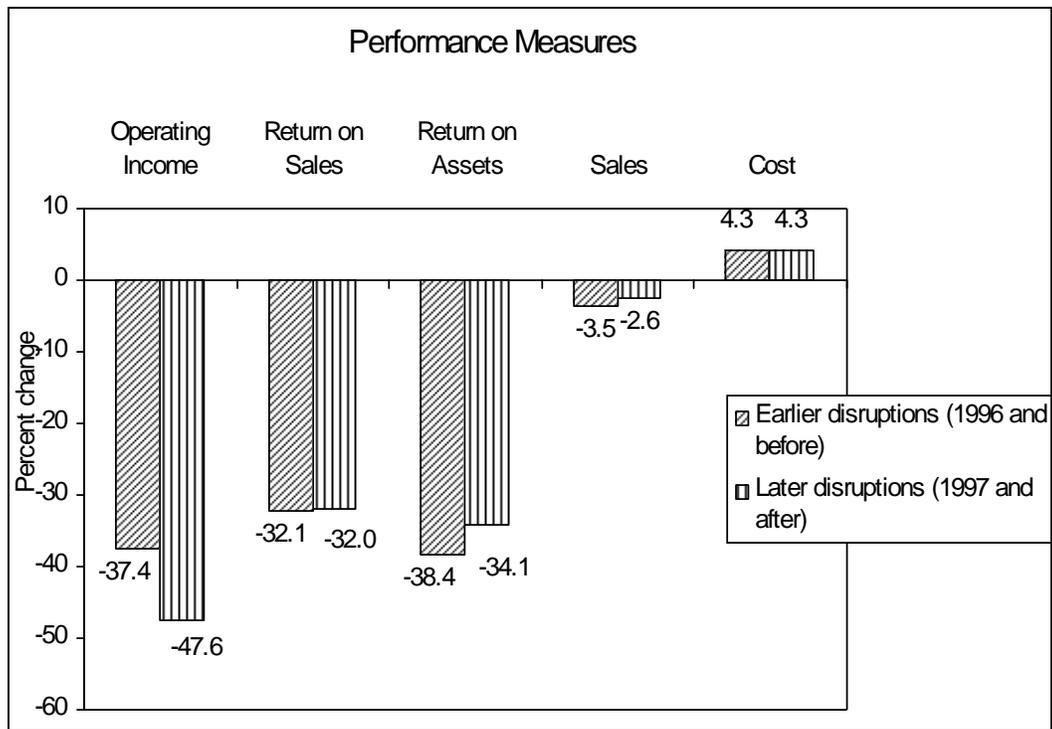


Figure 28: Control-adjusted changes in profitability related measures. Results for various time periods are reported for the time period that begins four quarters before the disruption announcement and ends during the quarter of the disruption announcement.

XIII. Drivers of supply chain disruptions

The historical view of corporate performance destruction due to supply chain disruptions is valuable because it provides firms with a sense of the economic effect of poor supply chain performance. The evidence clearly indicates that ignoring the possibility of supply chain disruptions can have devastating economic consequences. As one reflects on this evidence, a natural question is what are the primary drivers of supply chain disruptions? Given the recent heightened awareness of the risk of supply chain disruptions many experts have offered insights into the factors that can increase the chances of disruptions. Some of these major factors are discussed next with the intention that these factors can serve as guideline for managers as they assess the chances of disruptions in their supply chains. The chances of experiencing disruptions are higher now and in the future than in the past because of some recent trends and practices in managing supply chains:

- **Competitive environment:** There is no doubt that most industries are facing a vastly different competitive environment today than a decade or so ago. Today's markets are characterized by intense competition, very volatile demand, increased demand for customization, increased product variety, and short product life cycles. These trends are expected to intensify in the future. These conditions make it very challenging to match demand with supply. In particular, firms are facing increasing difficulty in forecasting demand and adjusting to unexpected changes in product life cycles and changing customer preferences.
- **Increased complexity:** The complexity of supply chains have increased due to global sourcing, managing large number of supply chain partners, need to coordinate across many tiers of supply chains, and dealing with long lead-times.

This increased complexity makes it harder to match demand and supply, thereby increasing the risk of disruptions. The risk is further compounded when various supply chain partners focus on local optimization, when there is lack of collaboration among supply chain partners, and when there is lack of flexibility in the supply chain.

- **Outsourcing and partnerships:** Increased reliance on outsourcing and partnering has heightened interdependencies among different nodes of the global supply networks and increased the chances that a disruption or problem in one link of the supply chain can quickly ripple through the rest of the chain, bringing the whole supply chain to a quick halt. While many experts have talked about the virtues of outsourcing and partnerships, for these to truly work well it is important that supply chain partners collaborate, share information and plans, and have visibility in each other's operations. Such changes require major investments in connected information systems, changes in performance metrics, commitment to share gains, and building trust among supply chain partners, all of which are not easy to achieve.
- **Single Sourcing:** Single sourcing strategies have reduced the purchase price and the administrative costs of managing the supplier base, but may have also increased the vulnerability of supply chains if the single-source supplier is unable to deliver on time.
- **Limited buffers:** Focus on reducing inventory and excess capacity and squeezing slack in supply chains has more tightly coupled the various links leaving little room for errors. Just-in-time delivery and zero inventory are

commonly cited goals but without careful consideration of the fact that these strategies can make the supply chain brittle.

- **Focus on efficiency:** Supply chains have focused too much on improving efficiency (reducing costs). A December 2002 report from Forrester indicates that 24 of the 26 senior supply chain executives indicated that improving operational efficiency is their top supply chain priorities while only 2 out of 26 indicated that making supply chain more flexible to manage risk is their top priority. Firms are responding to the cost squeeze at the expense of increasing the risk of disruptions. Most firms do not seem to consider the inverse relationship between efficiency and risk. Strategies for improving efficiency can increase the risk of disruptions.
- **Over-concentration of operations:** In their drive to take advantage of economies of scale, volume discounts, and lower transaction cost, firms have over-concentrated their operations at a particular location, or with their suppliers or customers. Over-concentration reduces the flexibility of the supply chain to react to changes in the environment and leads to a fragile supply chain that is susceptible to disruptions.
- **Poor planning and execution:** Poor planning and execution capabilities result in more incidents of demand-supply mismatches. Plans are often too aggregate, lack details, and are based on inaccurate inventory and capacity information. Lack of good information systems hinders the ability of the organization to be aware of what is happening. Lack of forward looking metrics affects the ability of firms to anticipate future problems and be pro-active in dealing with these problems. Firms also have limited visibility into what is

happening in upstream and downstream supply chain partners. Most firms have limited abilities and capabilities to identify and manage supply chain exceptions. This is further compounded by the lack of synchronization and feedback between supply chain planning and supply chain execution.

XIV. What can firms do to mitigate the chances of disruptions?

There is no doubt that many of the above-mentioned practices and trends have led to improvements in supply chain performance and profitability. Nonetheless, they may have also contributed to supply chains becoming more susceptible and vulnerable to disruptions. The challenge therefore is to devise approaches that can deal more effectively with disruptions, while not sacrificing efficiency. Some of these approaches are briefly outlined below:

- **Improving the accuracy of demand forecasts:** One of the primary reasons for demand supply mismatches is inaccurate forecasts. Bringing some quantitative rigor to forecasting can certainly help improve the accuracy and reliability of forecasts. Firms should consider not only the expected demand forecast but also the demand forecast error (variance) in developing plans. This would give planners an idea of what kind of deviation may happen from the mean value. Firms should also recognize that long-term forecasts are inherently less accurate than short-term forecasts as well as the fact that disaggregate forecasts are less accurate than aggregate forecasts. These considerations will enable planners to look more carefully at the forecasts they receive from sales and marketing. Forecasts often go bad when firms do not dynamically adjust forecasts, ignore background noise, and fail to consider events outside their own

organizations that could have a material effect on forecasts. Furthermore, firms often make forecasts assuming static lead times, transit time, capacity, and transportation and distribution routes. These assumptions must constantly be questioned to make adjustments as and when needed. Long planning time horizons that are frozen also makes it harder to develop accurate forecasts.

- **Integrate and synchronize planning and execution:** Firms have become sophisticated in their planning activities. But plans are often insulated from execution reality. In many cases plans are tossed over the wall for execution. Managers responsible for execution make adjustments to these plans to reflect current operating conditions. Such adjustments can grow over time but are seldom communicated to the planners, resulting in lack of integration between development and execution of plans. By better coordinating and integrating planning and execution many of the problems with supply demand mismatches can be avoided.

- **Reduce the mean and variance of lead time:** Forecasting inaccuracy and disconnect between planning and execution can be particularly devastating when lead times are long and highly variable. Reducing the mean and variance of lead time can help reduce the level of uncertainties in the supply chain. Some of the following practices can help reduce the mean and variance of lead times:

- Remove non-value added steps and activities
- Improve the reliability and robustness of manufacturing, administrative and logistics processes
- Pay close attention to critical processes, resources, and material

- Incorporate dynamic lead-time considerations in planning and quoting delivery times
- **Collaborate and cooperate with supply chain partners:** Although the concepts of collaboration and cooperation among supply chain partners have been around for a long time, achieving this has not been easy. The evidence presented in this study provides an economic rationale why supply chain partners must engage in these practices. The precursor for collaboration and cooperation is developing trust among supply chain partners, agreeing upfront on how to share the benefits, and showing a willingness to change from the old mindset. Once these elements are in place, supply chain partners must do joint decision making and problem solving, as well as share information about strategies, plans, and performance with each other. These activities can go a long way in reducing information distortion and lack of synchronization that currently plague supply chains and contribute to disruptions.
- **Invest in Visibility:** To reduce the probability of disruptions, firms must be fully aware of what is happening in their supply chain. This includes internal operations, customers, suppliers, and location of inventory, capacity, and critical assets. The following may be needed to develop visibility:
 - Identify and select leading or forward looking indicators of supply chain performance (suppliers, internal operations, and customers)
 - Collect and analyze data on these indicators
 - Set benchmark levels for these indicators
 - Monitor these indicators against the benchmark

- Communicate deviations from expected performance to managers at the appropriate levels on a real time basis
- Develop and implement processes for dealing with deviations
- **Build flexibility in the supply chain:** Firms must make careful and deliberate decisions to build flexibility at appropriate points in their supply chains to enhance responsiveness. There are multiple dimensions of flexibility and what will be appropriate for a firm depends on its operating environment.
 - **Building flexibility on the product design side:** Standardization, modularity, and use of common parts and platforms can offer the capability to react to sudden shift in demand and disruptions in delivery in parts.
 - **Building sourcing flexibility:** This can be achieved by using flexible contracts as well as use of spot markets to purchase parts and supplies. Spot markets can be used to both acquire parts to meet unexpected increase in demands as well as dispose of excess inventory if demand is below expectation.
 - **Building manufacturing flexibility:** This can be accomplished by acquiring flexible capacity that can be used to switch quickly among different products as the demand dictates. Firms should also consider segmenting their capacity into base and reactive capacity, where the base capacity is committed earlier to products whose demand can be accurately forecasted and reactive capacity is committed later for products where forecasting is inherently complex. Such would be the

case for products with short product life cycles as well as products with very volatile demand. Late differentiation of products can also be used as a strategy to increase manufacturing flexibility.

- **Postponement strategy:** Postponement or delayed differentiation is a strategy that delays product differentiation at a point closer to the time when there is demand for the product. This involves designing and manufacturing standard or generic products that can be quickly and inexpensively configured and customized once actual customer demand is known. By postponing differentiation of products, the chances of producing products that the market may ultimately not want are minimized, thereby reducing the chances of demand-supply mismatches. Key crucial success factors for implementing this strategy include:

- Cross-functional teams that represent the design and manufacturing functions
- Product and process reengineering to increase standardization
- Modularity
- Common parts and platforms
- Collaboration with customers and suppliers
- Performance measures and objectives that resolve conflicts and ensures accountability

- **Invest in technology:** Investment in appropriate technology can go a long way in reducing the chances of disruptions. Web based technologies are now available that can link databases across supply chain partners to provide visibility

of inventory, capacity, status of equipment, and orders across the extended supply chains. Supply chain event management systems have the ability to track critical events and when these events do not unfold as expected send out alerts and messages to notify appropriate managers to take corrective actions. This enables the firm to identify supply chain problems earlier rather than later and operate in a proactive rather than reactive mode. RFID technology has the promise to improve the accuracy of inventory counts as well as provide real time information on the status of orders and shipments in transit and what is being purchased by customers. Such access to real time information alleviates information distortions and provides true demand and supply signals, all of which can reduce the chances of demand-supply mismatches.

XV. Building capabilities to manage the risk of supply chain disruptions

Although there are a number of strategies that firms can use to mitigate the chances of disruptions, which of these would be appropriate for a particular firm depends on the firm's operating environment. To identify what strategies to adopt, firms need a systematic process for risk management that is carefully and regularly applied. The process should be championed at the highest executive level as this is critical for bringing about awareness of the importance of managing disruption risk. A broad plan for developing and implementing such a process could be as follows:

1. Assemble a cross-functional team of risk experts: In most organizations, risk management is housed at the corporate level in insurance, legal and audit services. But supply chain disruption risks require a different type of arrangement. The knowledge of supply chain risks

lies in marketing, operations, procurement, logistics, and information technology. Thus, the cross-functional team must include members from these areas as they have dealt in the past with disruptions and have sufficient experience to identify and quantify risks. To provide credibility and visibility to the team, top management must support and champion the team's activities and efforts by making a case for the importance of risk considerations and driving changes that mitigate risks.

2. Characterize the major sources of risk: The cross-functional team must regularly scan the internal and external environment to identify the vulnerable points of their supply chain. This involves identifying the primary sources of risk, estimating the probability of each risk happening, estimating the financial impact of the risk, the amount it would cost to recover from the risk, and the amount of time it would take to recover from the risk. Precise estimates on these issues may not be easy to get and therefore as a first step it would be appropriate to gather some qualitative data such as high or low frequency of occurring, high or low financial impact, and easy or hard to recover etc.

3. Assess and prioritize risks: Once the primary sources of risk have been identified and agreed upon, the next step is to assess and prioritize the risks that should be of serious concern to the firm. Top management and the board should be made aware of the high risk issues. Various alternatives should be considered to mitigate the high risk factors. Such alternatives include developing contingency plans to deal with the risk should it surface, options for spreading risks through insurance, forward contracts, flexible contracts, and making organizational changes in how the supply chain is designed and operated so that these risks are mitigated in the future.

4. Monitor risk and take actions as needed: Once the primary risks issues have been identified and contingency plans have been developed, firms should set a system to monitor

risks. Leading indicators need to be tracked, control limits need to be set to determine out of control conditions, two-way communication with supplier and customers must be done on a continuous basis, and visibility systems must be in place. When risks surface the appropriate contingency plans are activated and the effectiveness of these plans in mitigating the risk is continuously monitored.

5. Improve the risk management process: Firms must continuously strive to improve their risk management processes. As and when risk is dealt with, effort must be made to document the outcomes of the risk mitigation plans and highlight what worked and what did not work. These lessons should be shared across the organizations and used to improve the risk management process. Benchmarking a firm's process against other firms that have well functioning risk management process can identify best practices and help make a firm's process more robust and effective.

XVI. Summary

The evidence presented in this report makes a compelling case that ignoring the risk of supply chain disruptions can have serious negative economic consequences. Based on a sample of more than 800 supply chain disruption announcements, the evidence indicates that firms that suffer supply chain disruptions experience 33 to 40% lower stock returns relative to their benchmarks, 13.5% increase in share price volatility, 107% drop in operating income, 7% lower sales growth, and 11% increase in costs. By any yardstick these are very significant economic losses. More importantly, firms do not quickly recover from these losses. The evidence indicates that firms continue to operate for at least two year at a lower performance level after

experiencing disruptions. Given the significant economic losses, firms cannot afford such disruptions even if they occur infrequently.

The evidence presented in this study underscores why supply chain management issues deserve close attention by senior executives and board members. Heightened scrutiny of corporate governance makes executives more directly responsible for earnings forecasts and prediction. To the extent that supply chain disruptions can devastate corporate performance, senior executives must be fully aware of the performance of their supply chains.

As discussed in the report, overemphasis on efficiency and removing slack from the system can make supply chains brittle, unreliable, and non-responsiveness. While efficient and lean supply chains are desirable objectives, they should not come at the expense of reliability and responsiveness. There is a trade-off between efficiency of supply chains and risk of disruptions within supply chains.

It is quite common to find practitioner and academics talk about changes in supply chain management practices and investments in terms of their effect on efficiency and cost savings. Risk issues are often ignored because they cannot be easily quantified. Yet the evidence presented in this report strongly suggest that many times investments in supply chains should be undertaken not because they reduce costs but because they increase the reliability and responsiveness of supply chains. Such investments should be viewed as insurance against avoiding shareholder value destruction should disruptions happen. Given the evidence presented in this report, senior management must ask the question of whether they can afford not to proactively prevent and manage supply chain disruptions risk.

XVII. Appendix I: Methodology used to estimate stock price performance

The basic idea in long-term stock price studies is to estimate abnormal returns for a sample of firms that have experienced the same kind of event, and then test the null hypothesis that the abnormal returns over the period of interest are equal to zero. An abnormal return is the difference between the return on a stock and the return on an appropriate benchmark, where the benchmark is chosen to control for factors that are known to explain normal stock returns. The abnormal return is the return that can be attributed to the event under consideration, and hence measures the effect of the event. The idea is that after controlling for the known factors, whatever remains unexplained is deemed as abnormal and can be attributed to the event under consideration. The current consensus seems to be that abnormal returns should be computed after controlling for size, market-to-book ratio, and prior performance.

Another critical issue with long-term stock price studies is the interpretation of the statistical significance of the observed long-run abnormal returns. Test statistics from many commonly used methods (such as comparing to S&P 500 Index) are severely mis-specified making it hard to judge the true significance of observed abnormal returns. Recent academic studies suggest that abnormal returns computed using matching portfolios or one-to-one matching give well-specified tests. Both these approaches are briefly described next.

Abnormal returns using matched portfolios

The matching portfolio approach computes abnormal returns using as benchmark portfolios of firms that are similar in size, market-to-book ratio of equity, and prior performance. This approach is implemented using the following three-step procedure:

Step 1: In each month, all eligible NYSE firms are sorted into deciles according to their market value of equity. Next all AMEX and NASDAQ firms are placed into the appropriate size portfolio. The smallest size decile portfolio is further divided into quintiles, resulting in 14 size portfolios. Each portfolio is further divided into quintiles according to their market-to-book ratio of equity, resulting in 70 portfolios. Each portfolio is further divided into three portfolios based on the stock price performance of firms in that portfolio over the previous year, resulting in 210 portfolios for each month where firms in each portfolio are similar in terms of size, market-to-book ratio, and prior performance.

Step 2: In step 1, each sample firm has been assigned to a portfolio. The portfolio that a sample firm is assigned to 12 months before the month of the announcement date (the beginning of the measurement period) is identified. Since all other firms in this portfolio are similar to the sample firm on size, market-to-book ratio, and prior performance, all these firms can be considered as matched to the sample firm. The portfolio assignment and hence the set of matched firms for a sample firm remains the same over the three-year time period.

Step 3. The buy-and-hold return for each sample firm is computed. If the sample firm is delisted before the end of a time period, the buy-and-hold return stops on the delisting date of the sample firm. The buy-and-hold return of each matched firm in the portfolio that the sample firm is assigned to is also computed over the same time period. If a matching firm delists prior to the end of the period or before the sample firm's delisting date, whichever is earlier, the overall stock market's value-weighted return is spliced into the calculation from the day after the matched firm's delisting date. This assures that the buy-and-hold return of the sample and matched firms are computed over the same time period. The benchmark return for each sample firm is then the average of the buy-and-hold returns of all its matched firms in its assigned

portfolio. Abnormal performance is the difference between the return of the sample firm and the return to its assigned portfolio.

Abnormal returns using one-to-one match samples

In the one-to-one matching approach each sample firm is matched to an appropriately chosen control firm. The potential candidates for matching to a sample firm are those firms that belong to the portfolio that the sample firm is assigned to in the portfolio matching approach. This ensures that the matched firm will at least be similar to the sample firm on size, market-to-book ratio, and prior performance. Three different one-to-one control samples are created as follows:

1. Select the firm that is closest in size to the sample firm from the sample firm's assigned portfolio (Size Matched).
2. Select the firm that is closest in terms of prior performance to the sample firm from the sample firm's assigned portfolio (Performance Matched).
3. Select the firm that has the best matching on SIC code to the sample firm from the sample firm's assigned portfolio. If at least a one-digit match is not possible, the sample firm is dropped from the analysis (Industry Matched).

The abnormal return for a sample firm is the difference between its buy-and-hold return and that of the control firm.

XVIII. Appendix II: Methodology used to estimate changes in share price volatility

The effect of supply chain disruptions on share price volatility is examined by comparing the standard deviations of stock returns before and after the disruption announcement date. Standard deviation of stock returns is estimated for four years, starting two years before through two years after the disruption announcement. Each year consists of 250 trading days.

Many studies that consider the effect of corporate events on risk changes perform their analysis based on a comparison of the risk levels of sample firms before and after the event date. This approach could misestimate the true risk changes as risk can be influenced by certain macro factors that may have nothing to do with the event under consideration. Such factors could include interest rates, investor sentiments, consumer confidence, market expectations, and global business environments etc. To control for such factors, the percent changes in the standard deviations of stock returns of the sample firms are compared against that of a matched control sample. In other words the abnormal change in standard deviations of stock returns is estimated. For this purpose, the control sample used are the same ones used to estimate the buy-and-hold abnormal returns calculation using one-to-one matching approach (see Appendix I).

XIX: Appendix III: Methodology used to estimate changes in profitability

To provide a benchmark for the performance of the sample firms in the absence of disruptions, and to control for potential industry and/or economy wide effects, the performance of each firm in the sample is compared against an appropriately chosen control firm. It is reasonable to assume that firms in the same industry and of similar size are subject to similar economic and competitive factors. Thus, controls are chosen to be similar in size and industry characteristics of the sample firms. The control-adjusted (or abnormal) change in performance, the difference between the change in performance of sample and control firms is estimated and tested for statistical significance.

The matching process chosen matches on size and SIC code, which is commonly used in this type of analysis. A composite measure of size where sales and assets each are equally weighted is used.

To control for size and industry, three control samples are generated where each control sample is designed to address a specific potential bias or weakness in the others. In the first control sample, referred to as industry-size-matched control, each sample firm is matched to a control firm that has sufficient financial data available, has at least the same three-digit SIC code, and is closest in size, with the constraint that the ratio of size of the sample firm and control is always less than a factor of 3.

The second control sample, referred to as industry-matched control, attempts to find a control firm that has sufficient financial data available, has at least the same three-digit SIC code, and is closest in size. The key difference between this control sample and industry-size-matched control sample is that we do not put any constraint on the closeness of size matches.

The third control sample, referred to as most-matched, attempts to find a control firm that has sufficient financial data available, has at least the same two-digit SIC code, and is closest in size. The key difference between this control sample and industry-matched control sample is that we allow for two-digit SIC code matches.