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Association Between Supply Chain Glitches and Operating Performance

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This paper empirically documents the association between supply chain glitches and operating performance. The results are based on a sample of 885 glitches announced by publicly traded firms. Changes in various operating performance metrics for the sample firms are compared against a sample of control firms of similar size and from similar industries. In the year leading up to the announcement, the control-adjusted mean percent changes in operating income, return on sales, and return on assets for the sample firms are −107%, −114%, and −92%, respectively. During this same period, the control-adjusted changes in the level of return on sales and return on assets are −13.78% and −2.32%, respectively. Relative to controls, firms that experience glitches report on average 6.92% lower sales growth, 10.66% higher growth in cost, and 13.88% higher growth in inventories. More importantly, firms do not quickly recover from the negative economic consequences of glitches. During the two-year time period after the glitch announcement, operating income, sales, total costs, and inventories do not improve. We also find that it does not matter who caused the glitch, what the reason was for the glitch, or what industry a firm belongs to—glitches are associated with negative operating performance across the board.

Key words: supply chain glitches; empirical analysis; operating performance
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1. Introduction

Supply chain glitches, an indication of demand and supply mismatches, are receiving increased visibility and coverage in both the business and the academic press. Recent supply chain problems at Sony, Cisco, and Ericsson have been chronicled in detail by *The Wall Street Journal* (Thurm 2001, Tran 2000, and Latour 2001). Academicians and practitioners are discussing the impact of supply chain glitches on performance, and are highlighting the need to adopt practices that can prevent glitches (Kilgore 2003, Radjou 2002, Cachon and Lariviere 2001, Lakenan et al. 2001, Lee et al. 1997, Fisher 1997). Although it is intuitive that glitches are likely to have a negative impact on profitability, there is little systematic analysis and documentation of the magnitude of these impacts in the literature. Most of what we have seen is anecdotal or based on case studies.

This paper provides empirical evidence of the association between glitches and operating performance. The glitches examined are those that result in production or shipment delays, or both. Based on a sample of 885 glitches announced by publicly traded firms during 1992–1999 and data from quarterly financial reports around the time of glitches, we associate glitches with changes in operating income, sales, cost structure, assets, and inventories. We examine how the impact of glitches varies by the reasons and the source of responsibility, industry, firm size, and the calendar time when glitches occurred.

The evidence presented in this paper is important for a number of reasons. As mentioned above, it fills a gap in the operations management literature regarding the financial consequences of demand-supply mismatches. Although the conventional belief is that supply-demand mismatches will have negative financial consequences, there is very little rigorous evidence on the magnitude and severity of those consequences.

Efficiency, reliability, and responsiveness of supply chains are key drivers of a firm's profitability. Kilgore (2003) and Radjou (2002) suggest that much of the supply chain management efforts in the recent past have focused on increasing the efficiency (lowering costs) of supply chain operations, and less on increasing the robustness and reliability of supply chains. This could partly be because, unlike efficiency, it is much harder to place a value on robustness and reliability. Glitches are an indication that a firm's supply chain is not reliable and robust. By associating

glitches with control-adjusted changes in operating performance, we provide an estimate of the value of reliable and robust supply chain performance.

The evidence presented in this paper also adds to the recent research that has begun to quantify the impact of supply chain management strategies and practices on operating performance. One stream of research has focused on developing mathematical models of supply chain issues to understand how alternate ways of managing supply chains affect capital costs, operating costs, inventories, and service levels (see, for example, Barnes-Schuster et al. 2002, Milner and Kouvelis 2002, Taylor 2002, Aviv 2001, Cachon and Lariviere 2001, Cachon and Fisher 2000). Another stream of research has attempted to empirically establish the relationship between supply chain practices and performance. The approach used is to develop conceptual and theoretical frameworks of the drivers of supply chain performance, identify supply chain practices, use surveys to measure the intensity with which these practices are implemented, and link these to performance changes reported by survey respondents (see, for example, Rosenzweig et al. 2003, Frohlich and Westbrook 2001, Narasimhan and Jayaram 1998, Shin et al. 2000). Although significant research has been done on the relationship between supply chain performance and financial performance, most of the existing evidence is based on hypothetical or self-reported data. Hence, it is not clear how well the evidence correlates to actual performance.

This paper also extends recent research that has begun to use secondary data to link supply chain effectiveness to firm performance. Hendricks and Singhal (2003, 2005) estimate the shareholder value and risk effects of supply chain glitches. They estimate that, after adjusting for market trends, stock prices drop by nearly 10% when glitches are publicly announced and about 40% over the long term. They also find that glitches are associated with a significant increase in the risk of the firm. However, it is not clear whether the losses are caused by the market's assessment of the impact of glitches on operating performance, or by the market's overreaction to the news of glitches. The results of this study provide evidence on whether the stock market reaction to glitches is consistent with the association of glitches with operating performance.

The next section discusses how glitches negatively affect operating performance. Section 3 describes the collection of the sample and various sample statistics. Section 4 describes the methodology. Section 5 presents results on the overall association of glitches with operating income, sales, total costs, total assets, and inventories. Section 6 provides descriptive results on how the association of glitches with operating performance varies by source of responsibility for glitches, reasons for the glitches, firm size, various industry groups, and the calendar time when the glitch occurred. The final section summarizes the paper and suggests future research directions.

2. The Negative Consequences of Supply Chain Glitches

Supply chain glitches indicate a mismatch between demand and supply. Fisher and Raman (1996), Fisher (1997), Handfield and Nichols (1999), Lee et al. (1997), and Simchi-Levi et al. (2000), among others, have discussed the negative economic consequences of mismatches, much of which centers around how mismatches affect revenues, costs, and asset utilization. Glitches are likely to adversely affect the short and long-term profitability of the firm.

Supply chain glitches can lead to both short- and long-term loss in sales and market share, lower sales price due to markdowns of excess inventories, and could prevent the firm from capitalizing on strong market demand due to unavailability of products. Glitches can negatively impact customer service if customers are unable to get the products they want at the time they want them, resulting in higher customer dissatisfaction and lower customer loyalty. Glitches can hurt the reputation and credibility of the firm, causing customers not to consider the firm as a possible source for meeting their needs. Overall, glitches are likely to decrease net sales.

On the cost side, glitches can increase the costs associated with expediting, premium freight, obsolete inventory, additional marketing, and penalties paid to the customer. Furthermore, the loss of reputation and credibility associated with glitches may require firms to increase their public relation expenses to reinstate its credibility and reputation. It can also make it more expensive to raise capital, because investors may ask for a higher premium to lend to firms whose credibility and reputation is questionable. Overall, glitches are likely to increase costs.

Glitches can negatively impact the productivity and utilization of assets. In some cases equipment may be overutilized and in other cases it may be underutilized. The firm can end up with inventory imbalances. Overall, glitches could lead to poor asset and inventory performance.

The above discussion suggests that supply chain glitches will have negative economic consequences. We test the following hypotheses (all stated in alternative form):

HYPOTHESIS 1. *Supply chain glitches will be associated with a decrease in profitability.*

HYPOTHESIS 2. *Supply chain glitches will be associated with a decrease in net sales.*

HYPOTHESIS 3. *Supply chain glitches will be associated with an increase in costs.*

HYPOTHESIS 4. *Supply chain glitches will be associated with negative asset and inventory performance.*

To test Hypothesis 1, we estimate the change in operating income (sales minus cost of goods sold minus selling and general administration expenses) that can be attributed to glitches. Other measures of profitability that we consider are changes in return on sales (ratio of operating income to sales) and return on assets (ratio of operating income to total assets). Change in net sales is used to test Hypothesis 2, changes in total costs (sum of cost of goods sold and selling and general administration expenses) is used to test Hypothesis 3, and total assets and total inventories (sum of raw material, work in process, and finished good inventories) are used to test Hypothesis 4.

3. Sample Selection Procedure and Data Description

The Wall Street Journal and the Dow Jones News Service are our primary sources for collecting the sample of firms that experienced supply chain glitches. The search, covering an eight-year period from 1992 to 1999, looked for announcements that dealt with production or shipping delays. We could have searched further back in time but were constrained by the fact that the version of the COMPUSTAT database we used provided quarterly data for only a 12-year time period. Key words used in the search included 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 eliminated the following types of announcements:

(1) If a firm that made the announcement had insufficient financial information on COMPUSTAT.

(2) If a firm made multiple glitch announcements within 12 quarters of each other, then the more recent glitch announcements were excluded from the analysis to avoid overlapping periods. As discussed in §4, for each glitch we examine the performance starting four quarters before the quarter of the glitch announcement through eight quarters after the quarter of glitch announcement. Thus, including glitches that occurred within 12 quarters of each other would cause overlapping periods, with the performance during the overlapping period being counted more than once in the overall averages, which could potentially bias our results.

The final sample consists of 885 announcements. Examples of some announcements are:

- "Sony Sees Shortage of PlayStation 2s for Holiday Season," *The Wall Street Journal*, September 28, 2000.
- "Boeing Pushing for Record Production, Finds Parts Shortages, Delivery Delay," *The Wall Street Journal*, June 26, 1997.
- "Apple Computer Inc. Cuts 4th-period Forecast Citing Parts Shortages, Product Delays," *The Wall Street Journal*, September 15, 1995.

Table 1 presents statistics on the sample for different quarters around the announcement quarter. In the quarter before the announcement quarter, the mean (median) observation represents a firm with quarterly sales of nearly \$398 million (\$23 million), total assets of \$1,828 million (\$78 million), and operating income of \$36 million (\$0.9 million). Figure 1 presents the distribution of the sample firm by total assets. The sample represent considerable dispersion in size, with nearly 38% of the sample firms reporting total assets below \$50 million and nearly 16% reporting total assets above \$500 million. Figure 2 presents the number of announcements by year. Nearly 62% of the announcements were made during 1996–1999 with the remainder made during 1992–1995.

Out of the 885 announcements, 253 announcements did not give any information on who is responsible for the glitches or the reasons for glitches. Panel A of Table 2 indicates that the responsibility for the glitches is solely attributed to internal sources in 295 cases, to customers in 121 cases, and to suppliers in 123 cases, and to other sources (government, regulatory agencies, and nature) in 44 cases. Panel B of

Table 1 Descriptive Statistics for the 885 Supply Chain Glitch Announcements

	Four quarters before the announcement quarter			Quarter before the announcement quarter			Four quarters after the announcement quarter		
Quarter performance	Mean	Median	Std. dev.	Mean	Median	Std. dev.	Mean	Median	Std. dev.
Sales (million \$)	384.8	20.6	2,586.4	397.9	22.7	2,703.8	467.1	25.8	2,945.0
Total assets (million \$)	1,859.2	71.1	15,725.9	1,828.4	77.9	14,827.8	2,257.1	85.3	17,714.6
Operating income (million \$)	32.3	1.6	258.7	36.1	0.9	286.2	41.2	0.7	305.4
Return on sales (%)	−35.4	6.9	532.0	−21.7	3.8	220.4	−86.5	3.3	1,919.9
Return on assets (%)	1.3	2.3	7.3	−0.7	1.2	7.4	−1.2	1.0	9.9
Total costs (million \$)	320.8	19.6	2,186.7	364.7	21.9	2,449.2	427.6	23.4	2,693.9
Total inventory (million \$)	164.6	12.3	921.0	172.2	14.5	935.6	183.3	16.0	936.7

Figure 1 **Distribution of the Total Assets of Sample Firms in the Quarter Before the Announcement Quarter**

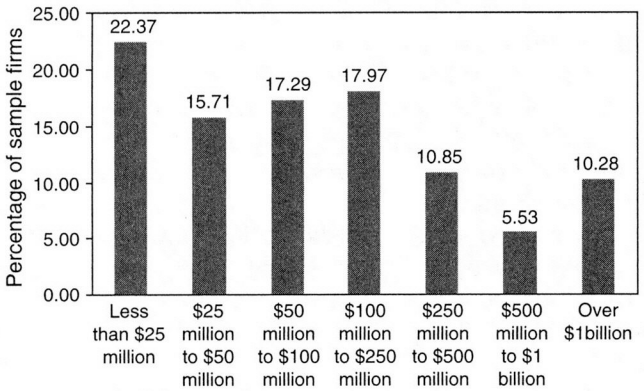


Table 2 indicates that parts shortages, ramping and rollout problems, last-minute changes requested by customers on their orders, various production problems, and development and engineering changes are the primary reasons cited for glitches.

Nearly 43% (379 out of 885) of the announcements convey information about other firm-specific events besides glitches. Furthermore, nearly 17% (151 out of 885) of the announcements can be classified as multiple-glitch announcements, because these announcements were followed by another glitch announcement within three years of the first announcement. As mentioned earlier, we excluded the later glitch announcements because including these would cause overlapping time periods, with the performance during the overlapping period being counted more than once in the overall statistics. However, these 17% of the announcements capture the effect of multiple announcements. Although the main results of the paper are based on the full sample, we will present results to test whether the association with operating performance of announcements with no other firm-specific events and other firm-specific events, and single and multiple announcements, is significantly different.

Figure 2 **Distribution of the 885 Supply Chain Glitch Announcements, by Year**

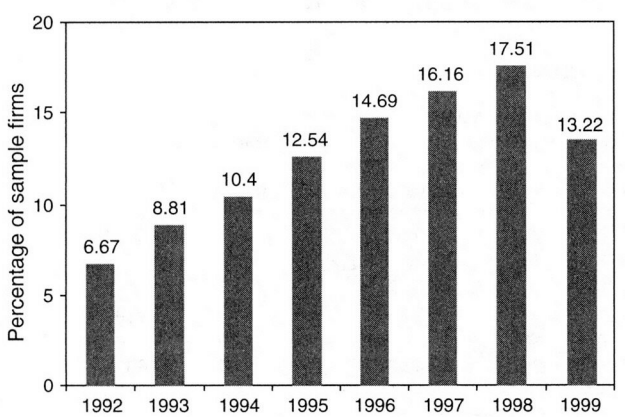


Table 2 **Statistics on the Primary Sources of Responsibility and Reasons for Supply Chain Glitches**

Responsibility	Number of announcements
Panel A. Responsibility for glitches	
Internal	295
Customers	121
Suppliers	123
Others[a]	44
Internal and supplier	12
Internal and customer	13
Internal and others	7
Customer and supplier	14
Supplier and other	2
Customer and other	1
None provided	253
Reasons	**Number of announcements**
Panel B. Reasons for glitches	
Parts shortages	171
Ramping up and rollout problems	84
Order changes by customers	76
Various production problems	70
Development and engineering changes	43
Quality problems	32
Weather-related problems	29
Capacity and equipment problems	19
Information technology problems	18
Regulatory approval delays	15
Project and program delays	12
Construction problems	10
Reorganization delays	10
None provided	253

[a]The other category includes government, regulatory, and nature as sources of responsibility.

4. Methodology

There are two major methodological issues that need to be addressed to estimate the association of glitches with operating performance. These issues relate to the period for measuring the changes in operating performance, and the methods used to adjust operating performance for the influence of industry- and economy-related factors.

4.1. Setting the Time Period for Measuring Performance

We examine operating performance both before and after the glitch announcement. Many firms reveal information about glitches as part of earnings announcements or preannouncements, or both, where the actual or expected earnings outcomes are attributed to glitches. Glitches are often a result of problems experienced over time; the announcement is an acknowledgement that the problems have occurred. Thus, some of the effect of glitches on operating performance has already been felt before the

announcement. Glitches can continue to affect operating performance even after the announcement, as customers and suppliers react to the glitch and adjust their plans accordingly. Furthermore, the ability of the firm to effectively deal with its customers and suppliers may continue to deteriorate, leading to poor operating performance after the glitch announcement. Given this, it makes sense to examine the performance both before and after the glitch announcement.

A review of a number of studies that have researched the impact of different types of corporate events on operating performance suggests that there are no theoretical or empirical guidance on what should be the appropriate period for examining performance (see Barber and Lyon 1996 for a list of some of these studies). Periods used have ranged anywhere from one year to 10 years. The choice of period depends on the events being researched, and rational choices made by researchers.

We examine the operating performance over a 13-quarter time period anchored around the quarter during which the glitch announcement is made. Specifically, we examine performance beginning four quarters before and ending eight quarters after the quarter of glitch announcement. Firms may have an incentive to disclose glitches when the negative consequences cannot be avoided. Thus, the impact of glitches is likely to be felt in the quarter of the announcement and the few quarters preceding it. By focusing on four quarters before the quarter of glitch announcement, we increase our ability to detect the negative consequences. The reason for focusing on the eight-quarter time period after the glitch announcement is to capture the continuing impact of glitches, if any, on performance, and also to test whether firms have recovered from the glitches.

To pool observations across time, for each firm in our sample we translate calendar quarters to event quarters as follows: The quarter when the glitch announcement is made is denoted as Quarter 0. The next (previous) quarter is Quarter 1 (Quarter −1), the quarter after (before) that is Quarter 2 (−2), and so on. Thus, the 4th quarter before the quarter of glitch announcement is Quarter −4 and the 8th quarter after the quarter of the glitch announcement is Quarter 8.

4.2. Generating Matched-Pair Control Samples to Control for Industry and Economy Effects

To control for potential industry or economy-wide effects, or both, that may have nothing to do with glitches, the performance of each sample firm is compared against an appropriately chosen control firm. The process for choosing controls is similar to that used in the literature (see, for example, Kaplan 1989, Dann et al. 1991, Denis and Denis 1993, Hendricks and Singhal 1997). Our approach for matching sample firms to control firms is as follows:

Step 1. We identify all firms that are covered by the quarterly COMPUSTAT over 1991–2001. This spans our analysis period when the year before the announcement quarter and two years after the announcement quarter are included. From this set, we remove all duplicate firms and firms with no data.

Step 2. We remove all sample firms from the set of firms generated in Step 1 to identify the set of firms that could be potential controls for the sample firms.

Step 3. We develop a program with the objective of matching each sample firm to the single best control firm from the set of control firms based on specific criteria. To prevent any cross-sectional dependencies, when a control firm is matched to more than one sample firm this control firm is assigned to the sample firm with the best matching, and the other sample firms that are matched to this control firm are set aside for matching in the next pass. Once a particular control firm is designated as a match to a particular sample firm, both these sample and control firms are removed from the next pass. In other words, a control firm is used only once and a sample firm matched to only one control.

Step 4. Step 3 is repeated until all sample firms are matched or no more matches can be found to meet the desired matching criteria.

Using the above approach, we create three different control samples. In the first control sample, referred to as *industry-size-matched control*, for each sample firm we identify the set of control firms that meet the following criteria:

Criterion 1. The control firm must have the same amount of data available as the sample firm over the sample firm's period of interest. For example, if a sample firm has data available over Quarters −3 to 6, then the control must have data available at least over this time period.

Criterion 2. The quarter-ending month of the control must be the same as that of the sample firm. This is done to ensure that the quarters are aligned. For example, we do not want to match a sample firm with a March quarter ending, with a control firm with a January quarter ending, because the accounting information for the March and January ending quarters would represent performance over different calendar time.

Criterion 3. The control firm has at least the same three-digit SIC code.

Criterion 4. The sales (total assets) of the control firm are within a factor of 3 of the sales (total assets) of the sample firms. Thus, if the sample firm has sales (total assets) of \$10 million, the control firm must have sales (total assets) between \$3.33 million and \$30 million.

Table 3 Comparison of the Characteristics of the Sample Firms and the Industry-Size-Matched, Industry-Matched, and Most-Matched Control Samples During the Quarter Before the Quarter of Glitch Announcement

	Industry-size-matched	Industry-matched	Most-matched
Number of sample firms to be matched	885	885	885
Number of sample firms (percentage of sample firms) matched	714 (81)	822 (93)	863 (98)
Mean (median) sales of matched sample firms (million $)	131.1 (20.74)	390.8 (22.2)	402.7 (22.9)
Mean (median) sales of matched control firms (million $)	120.8 (20.74)	141.83 (21.9)	177.6 (22.8)
t-statistic (Wilcoxon sign ranked *Z*-statistic) on the paired differences between the sales of sample and control firms	1.72 (0.34)	2.75*** (1.28)	2.54** (1.29)
Mean (median) total assets of matched sample firms (million $)	516.8 (70.8)	1,847.4 (75.2)	1,866.1 (80.7)
Mean (median) total assets of matched control firms (million $)	482.7 (72.7)	572.5 (76.3)	963.6 (77.7)
t-statistic (Wilcoxon sign rank *Z*-statistic) on the paired differences between the total assets of sample and control firms	1.21 (−0.63)	2.43** (−1.73)	1.53 (−1.59)
Industry matching statistics			
Percentage of firms matched at 4-digit SIC code	49	50	18
Percentage of firms matched at 3-digit SIC code	51	50	20
Percentage of firms matched at 2-digit SIC code	0	0	62

Notes. The level of statistical significance from zero is noted by $^{*}p \leq 0.05$, $^{**}p \leq 0.025$, and $^{***}p \leq 0.01$ for two-tailed tests.

For each control firm that meet the above criteria, we compute percentage error in sales and percentage error in total assets relative to the sample firm as

$$100 * [\text{absolute value}(\text{sales of sample} - \text{sales of control})] / [\max(\text{sales of sample}, \text{sales of control})],$$

$$100 * [\text{absolute value}(\text{assets of sample} - \text{assets of control})] / [\max(\text{assets of sample}, \text{assets of control})].$$

Our method of computation of percentage error does not depend on which is the sample firm and which is the control firm. It is symmetric in the sense that if the best match for a sample firm with $10 million in sales is a control firm with $15 million in sales, then a control firm with $10 million in sales is also the best match for a sample firm with $15 million in sales. The percentage error in sales and total assets are equally weighted to give the total percentage error. The control firm that has minimum total percentage error is assigned to the sample firm.

We are able to match 714 (80%) of the sample firms in the industry-size-matched control group. Because nearly 20% of the sample firms and, particularly, large firms are not matched in this control group, we generate a second control sample by setting the size factor to infinity (Criterion 4). In other words, we generate the initial set of potential controls for a sample firm without any constraints on the closeness on sales and total assets. In this control sample, referred to as industry-matched control, we are able to match 822 (93%) of the sample firms.

To further increase the number of sample firms that are matched, we generate a third control sample, referred to as *most-matched*, by relaxing the SIC code Criterion 3 used for the industry-matched control. We generate the initial set of potential controls for a sample firm by allowing at least a two-digit SIC code match. We are able to match 863 (98%) of the firms in this control sample.

Table 3 gives statistics to compare the characteristics of the matched sample and control firms for the three control samples. The median sales (total assets) of the three control samples and the matched sample firms are not different (two-tailed p values > 0.10). The mean sales (total assets) of the industry-size-matched control sample and the matched sample firms are not different (p values > 0.10). However, in the other two control samples, sample firms have significantly higher mean sales and total assets than the control firms (p values ≤ 0.025).

The percent of matches with the same three- and four-digit SIC codes are equally split in the industry-size-matched and industry-matched control samples. In the most-matched control samples, nearly 61% of the firms matched are matched at the two-digit SIC codes, with the rest split equally between three- and four-digit SIC code matches.

Barber and Lyon (1996) find that matching on prior performance can result in well-specified tests of control-adjusted performance. Strictly speaking, their findings are applicable to return on sales or return on assets and not for measures such as change in operating income, sales, total costs, total assets, and inventories that we also use in this paper. To reflect Barber and Lyon's (1996) findings in our analyses, we compare the performance of the sample and control firms in Quarter −4 to judge the quality of matching on prior performance, even though we do not explicitly use performance in our matching criteria. For the industry-size-matched and industry-matched control samples, the median of the paired differences in the level of return on sales (assets) between sample and control firms in Quarter −4 is not significantly different from zero (p values > 0.10), indicating that

the sample and control firms are well matched on prior performance. This is not the case for the most-matched control sample, because the median return on sales (assets) of the sample firms is higher than that of the control firms (p value ≤ 0.05). To further validate our results, we repeat our analyses for return on sales and return on assets using the approaches advocated by Barber and Lyon. These results are similar to the results using the three control samples, where prior performance is not used as an explicit matching criterion.

It is important to note that no matching process will be perfect, especially when a large number of firms are to be matched on multiple criteria. We are unaware of any systematic biases that may exist in our matching process. Although it is hard to get control samples that are perfect on all matching criteria, the three control samples together with the approach of Barber and Lyon should control for any unintended biases.

In reporting our results, we focus on the control-adjusted change in performance, which are the paired differences in the change in performance between the sample firms and their respective control firms. To illustrate how this is computed, consider the following example: Suppose that the return on assets for one of our sample firms drops from 10% in Quarter −4 to 7% in Quarter 0, a 30% drop. Suppose that during the same time period the return on assets of the control assigned to this sample firm increased from 10% to 11%, a 10% increase. In this case, the control-adjusted percentage change in return on assets is −40% (−30% to −10%). The change in performance can also be computed using the change in the level of performance. In the above example, change in the level of return on assets for the sample firm is −3% and for the control it is 1%, resulting in a control-adjusted change in the level of return on assets of −4%. Such changes are computed for all sample firms that are matched in each control sample.

Because percent changes are meaningless if the denominator used in the computation is negative, we exclude from our analyses those firms (both sample and control firms) whose performance at the beginning of the measurement period is negative. This is a possibility with income–based measures such as operating income, return on sales, and return on assets. Therefore, we have fewer observations for percent change in operating income–based measures than for percent change in sales, total cost, total assets, and inventory. Excluding base quarters with negative operating income could potentially bias the results. To control for this we also estimate the change in the level of operating return on sales and assets, which does not have the negative denominator bias.

To control for outliers that can unduly influence the mean values, particularly when accounting measures are used, all results are reported after symmetrically trimming the data at the 1% level in each tail. The main conclusions are similar using capping (or winsorizing) at the 1% level in each tail. T-statistics test whether the mean values of control-adjusted performance variables are significantly different from zero. To further control for outliers, we report the median values of control-adjusted performance variables as well as the percent of sample firms that experience negative control-adjusted performance. The Wilcoxon sign rank test is used to test whether the median is significantly different from zero, and the binomial sign test is used to test whether the percent of sample firms experiencing negative performance is significantly different from 50%. Consistency between these two nonparametric test statistics and the t-statistics would indicate that outliers are not driving the results. We measure the significance of results conservatively by reporting two-tailed tests of significance.

5. Empirical Results—Before and After the Supply Chain Glitch Announcements

5.1. Results for the Full Sample

Table 4 and Figure 3 present the results for the period that begins four quarters before the glitch announcement and ends during the quarter of the glitch announcement (Quarter −4 to Quarter 0) for the three different control samples. Because the three control samples give similar results, we use the results from the most-matched control samples in our discussion. All results presented are control adjusted.

Table 4 indicates that glitches are negatively associated with operating performance. The control-adjusted mean percent changes in operating income, return on sales, and return on assets are −107.43%, −114.67%, and −92.24%, respectively, all significantly different from zero (p values ≤ 0.01). Outliers are not driving the negative association in operating income–based measures. The median of the percent changes in operating income, return on sales, and return on assets are −42.47%, −32.02%, and −35.82%, respectively, all significantly different from zero (p values ≤ 0.01). The proportion of firms experiencing negative control-adjusted change in operating income is significantly higher than 50% (p values ≤ 0.01).

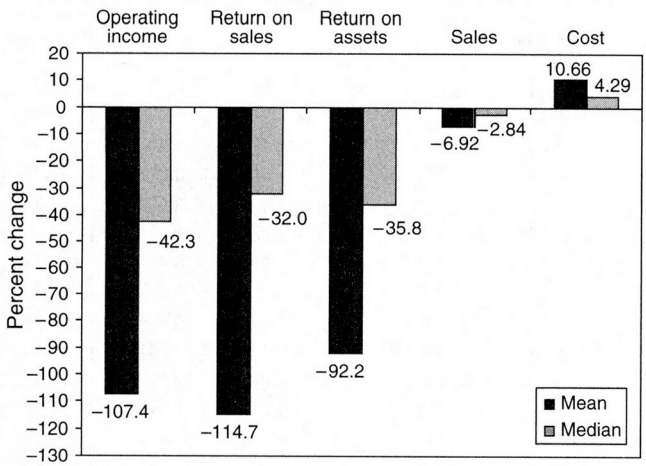
The percent changes in operating income–based measures are not driven by a potential negative denominator bias (exclusion of observations with negative base quarters for calculating percent changes). In Table 4, the mean (median) change in the level

Table 4 Change in Control-Adjusted Operating Performance of Sample Firms During the Year Before the Announcement of Glitches for the Three Different Matched Control Samples

Performance measures	Industry-size-matched control sample				Industry-matched control sample				Most-matched control sample			
	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.
Percentage change in operating income	432	−91.42 (−4.82)***	−36.13 (−7.33)***	65.97 (−6.65)***	500	−109.50 (−5.96)***	−39.16 (−8.08)***	66.60 (−7.42)***	517	−107.43 (−6.80)***	−42.27 (−8.56)***	66.54 (−7.52)***
Percentage change in return on sales	433	−77.56 (−3.97)***	−31.09 (−7.49)***	66.98 (−7.07)***	501	−100.45 (−5.01)***	−31.09 (−8.02)***	66.67 (−7.46)***	516	−114.67 (−6.16)***	−32.02 (−9.07)***	68.61 (−8.45)***
Percentage change in return on assets	434	−64.91 (−4.44)***	−31.68 (−7.27)***	65.67 (−6.67)***	501	−80.38 (−5.64)***	−36.05 (−7.95)***	65.87 (−7.10)***	515	−92.24 (−5.87)***	−35.82 (−8.66)***	66.80 (−7.62)***
Change in the level of return on sales	682	−12.12% (−5.92)***	−3.99% (−9.13)***	66.28% (−8.36)***	782	−13.73% (−6.56)***	−3.49% (−9.55)***	66.12% (−9.00)***	823	−13.78% (−7.05)***	−3.94% (−10.09)***	65.62% (−8.96)***
Change in the level of return on assets	681	−2.16% (−7.93)***	−1.21% (−8.47)***	64.76% (−7.83)***	782	−2.08% (−7.98)***	−1.18% (−8.68)***	64.20% (−7.94)***	824	−2.32% (−9.02)***	−1.36% (−9.30)***	63.84% (−7.94)***
Percentage change in sales	691	−7.17 (−2.41)**	−2.84 (−1.53)	52.32 (−1.41)	793	−8.01 (−3.17)***	−3.52 (−2.58)**	53.60 (−2.03)*	832	−6.92 (−2.98)***	−2.84 (−2.65)**	53.97 (−2.29)**
Percentage change in total costs	681	9.77 (8.23)***	4.36 (9.53)***	33.92 (−8.39)***	781	10.34 (8.91)***	3.95 (9.98)***	34.19 (−8.83)***	822	10.66 (9.07)***	4.29 (10.23)***	34.92 (−8.65)***
Percentage change in total assets	691	4.99 (1.68)	3.63 (2.38)**	46.02 (−2.09)*	796	7.16 (2.65)**	4.00 (3.04)***	45.61 (2.48)**	836	6.08 (2.39)**	3.06 (2.90)***	46.05 (−2.28)**
Percentage change in total inventory	586	14.69 (3.88)***	10.17 (5.03)***	39.77 (4.95)***	682	15.05 (4.67)***	10.39 (5.63)***	39.45 (−5.52)***	714	13.88 (4.38)***	9.59 (5.49)***	41.06 (−4.79)***

Notes. Results are reported for the period that begins four quarters prior to the glitch announcement (Quarter −4) and ends during the quarter of the announcement (Quarter 0). *T*-statistic for the mean, Wilcoxon sign rank test *Z*-statistic for the median, and the binomial sign test *Z*-statistic for the percentage negative are reported in parentheses. Percentage negative refers to the percent of sample firms whose change in performance is worse than that of their controls. The level of statistical significance from zero is noted by $^{*}p \leq 0.05$, $^{**}p \leq 0.025$, and $^{***}p \leq 0.01$ for two-tailed tests.

Figure 3 **Change in Control-Adjusted Operating Performance of Sample Firms During the Year Before the Announcement of Glitches Using the Most-Matched Control Sample**



of return on sales is −13.78% (−3.94%), whereas the mean (median) change in the level of return on assets is −2.32% (−1.36%). All these changes are significantly different from zero (p values ≤ 0.01).

The association between supply chain glitches and sales growth is negative (see Table 4). The mean (median) percent change in sales is −6.92% (−2.84%), significantly different from zero (p values ≤ 0.025). Nearly 54% of the sample firms experienced negative control-adjusted sales growth. Glitches also increase total costs. The mean (median) change in total costs is 10.66% (4.29%), significantly different from zero (p values ≤ 0.01). Nearly 65% of the sample firms experience an increase in total costs. The drop in sales together with the increase in total costs can explain the statistically significant drop in operating income–based measures.

Table 4 shows that the association between supply chain glitches and asset growth is positive. The mean (median) change in total assets is 6.08% (3.06%), significantly different from zero (p values ≤ 0.025). Normally, an increase in the asset base can be considered positive because it indicates positive growth. But this is not the case in the case of glitches because it indicates lower asset turnover—assets are increasing while sales are decreasing. Glitches are also associated with an increase in total inventories. The mean (median) change in the total inventory levels is 13.88% (9.59%), with nearly 59% of the sample firms experiencing an increase in their inventory. All these results are significantly different from zero (p values ≤ 0.01).

Tables 5 and 6 presents the results for the period after the glitch announcement. Specifically, Table 5 presents the results over the period that begins during the quarter of the glitch announcement and ends four quarters after the glitch announcement (Quarter 0 to Quarter 4), whereas Table 6 presents the results for the period that begins four quarters after and ends

Table 5 **Change in Control-Adjusted Operating Performance of Sample Firms During the First Year After the Announcement of Glitches for the Three Different Matched Control Samples**

Performance measures	Industry-size-matched control sample				Industry-matched control sample				Most-matched control sample			
	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.
Percentage change in operating income	317	−25.80 (−1.31)	−6.14 (−1.58)	54.89 (−1.74)	370	−7.42 (−0.37)	−6.09 (−1.58)	54.32 (−1.69)	395	0.94 (0.05)	−6.52 (−1.38)	52.66 (−1.06)
Percentage change in return on sales	316	−38.12 (−1.93)	−3.82 (−1.73)	51.27 (−0.46)	369	−20.61 (−1.16)	−1.41 (−1.51)	50.68 (−0.27)	394	−18.09 (−1.03)	0.09 (−1.50)	49.49 (−0.19)
Percentage change in return on assets	315	−22.34 (−1.14)	−8.32 (−1.38)	53.33 (−1.18)	368	−4.97 (−0.26)	−5.90 (−1.27)	52.72 (−1.04)	391	−6.36 (−0.41)	−4.62 (−1.25)	53.71 (−1.47)
Change in the level of return on sales	600	0.85% (0.46)	0.38% (0.51)	48.50% (−0.73)	697	1.49% (0.79)	0.20% (0.13)	49.07% (0.47)	730	6.46% (2.09)*	0.40% (0.47)	47.81% (−1.18)
Change in the level of return on assets	602	0.04% (0.16)	0.04% (0.57)	49.68% (0.16)	699	−0.11% (−0.42)	−0.01% (−0.11)	51.65% (−0.34)	733	0.12% (0.43)	0.05% (0.41)	49.79% (−0.11)
Percentage change in sales	606	−3.88 (−1.87)	−6.02 (−2.30)**	56.28 (−3.09)***	705	−2.77 (−0.14)	−6.21 (−2.31)**	52.17 (−3.27)***	739	1.00 (0.48)	−1.92 (−0.76)	51.69 (−0.92)
Percentage change in total costs	599	1.32 (1.17)	−0.21 (0.12)	51.09 (−0.53)	696	1.22 (1.16)	−0.05 (0.48)	50.44 (−0.23)	727	0.29 (0.25)	−0.28 (−0.07)	51.59 (−0.86)
Percentage change in total assets	612	−7.53 (−4.03)***	−4.16 (−3.79)***	56.05 (−2.99)***	713	−7.36 (−4.32)***	−4.36 (−4.00)***	52.25 (−3.33)***	747	−3.51 (−2.11)*	−1.81 (−1.95)	53.02 (−1.69)
Percentage change in total inventory	526	−5.13 (−1.98)*	−3.42 (−1.67)	53.05 (−1.40)	619	−6.62 (−2.79)***	4.63 (−2.39)**	54.60 (−2.29)**	645	−3.98 (−1.74)	−1.49 (−1.05)	51.01 (−0.51)

Notes. Results are reported for the period that begins during the quarter of the glitch announcement (Quarter 0) and ends four quarters after the glitch announcement (Quarter 4). T-statistic for the mean, Wilcoxon sign rank test Z-statistic for the median, and the binomial sign test Z-statistic for the percentage negative are reported in parentheses. Percentage negative refers to the percent of sample firms whose change in performance is worse than that of their controls. The level of statistical significance from zero is noted by $^{*}p \leq 0.05$, $^{**}p \leq 0.025$, and $^{***}p \leq 0.01$ for two-tailed tests.

Table 6 Change in Control-Adjusted Operating Performance of Firms During the Second Year After the Announcement of Glitches for the Three Different Matched Control Samples

Performance measures	Industry-size-matched control sample				Industry-matched control sample				Most-matched control sample			
	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.
Percentage change in operating income	245	21.16 (0.67)	−2.66 (0.23)	50.62 (−0.19)	288	14.36 (0.46)	2.11 (0.47)	49.64 (−0.12)	290	−23.09 (−0.97)	−8.32 (−1.43)	52.07 (−0.72)
Percentage change in return on sales	244	5.74 (0.17)	1.88 (0.63)	49.18 (−0.27)	287	7.01 (0.20)	1.49 (0.68)	49.17 (−0.27)	292	−36.19 (−1.50)	−3.49 (−0.92)	52.40 (−0.82)
Percentage change in return on assets	246	10.70 (0.34)	−2.33 (0.07)	51.63 (−0.51)	289	8.78 (0.27)	−1.30 (0.31)	50.87 (−0.30)	293	−25.44 (−1.05)	−6.58 (−1.45)	53.59 (−1.23)
Change in the level of return on sales	466	0.06% (0.03)	−0.12% (0.08)	50.43% (−0.19)	546	0.99% (0.56)	0.29% (0.66)	49.09% (−0.42)	574	−3.62% (−1.55)	−0.41% (−0.61)	52.27% (−1.09)
Change in the level of return on assets	471	−0.13% (−0.37)	−0.02% (0.18)	50.32% (−0.14)	550	0.12% (0.39)	0.10% (0.64)	49.28% (−0.13)	578	−0.04% (−0.14)	−0.05% (−0.24)	50.87% (−0.42)
Percentage change in sales	477	−0.40 (−0.16)	−1.93 (−0.61)	51.58 (−0.70)	558	0.78 (0.35)	−1.95 (−0.51)	51.62 (−0.76)	584	−3.06 (−1.35)	−3.87 (−1.59)	54.63 (−2.24)**
Percentage change in total costs	466	−0.03 (−0.02)	0.20 (−0.14)	49.58 (−0.18)	545	−0.56 (−0.51)	−0.41 (−0.78)	51.20 (−0.56)	572	1.05 (0.99)	0.41 (0.46)	47.91 (−1.00)
Percentage change in total assets	486	0.16 (0.08)	−3.04 (−1.52)	54.12 (−1.81)	568	−0.49 (−0.26)	−3.57 (−2.10)*	55.29 (−2.53)**	595	−2.63 (−1.37)	−5.14 (−2.72)***	46.05 (−3.81)***
Percentage change in total inventory	421	0.47 (0.16)	−5.42 (−1.68)	55.35 (−2.19)*	497	−2.20 (−0.83)	−5.91 (−2.52)**	56.14 (−2.73)***	515	−1.78 (−0.70)	−5.85 (−2.18)**	55.34 (−2.42)**

Notes. Results are reported for the period that begins four quarters after the glitch announcement (Quarter 4) and ends eight quarters after the announcement (Quarter 8). *T*-statistic for the mean, Wilcoxon sign rank test *Z*-statistic for the median, and the binomial sign test *Z*-statistic for the percentage negative are reported in parentheses. Percentage negative refers to the percent of sample firms whose change in performance is worse than that of their controls. The level of statistical significance from zero is noted by $^{*}p \leq 0.05$, $^{**}p \leq 0.025$, and $^{***}p \leq 0.01$ for two-tailed tests.

eight quarters after the glitch announcement (Quarter 4 to Quarter 8). These results provide insights into any persistence of the negative association of glitches on performance, and the extent and speed of recovery, if any, from glitches.

Table 5 indicates that, subsequent to the glitch announcement, there is no evidence of worsening or improvement in performance. Focusing on the results from the most-matched control sample, we see that some performance measures improve, whereas others worsen. However, except for 2 of the 27 reported statistics, all changes in operating metrics are insignificantly different from zero (p values > 0.05). Overall, in the year after the glitch announcement there is no difference between the changes in the operating income of the sample and control firms. This is further reinforced in Table 6, which gives the performance for Quarters 4 through 8 after the glitch announcement. The changes in operating income–based measures, sales, and total costs are insignificantly different from zero (p values > 0.05). There is weak evidence to suggest that during this period sample firms reduced total assets and total inventories.

The above results indicate that association of glitches with operating performance is negative and significant (Table 4). Furthermore, firms that experience glitches do not recover quickly from the negative performance (Tables 5 and 6). Firms start at a higher level of operating performance before glitches, glitches lower the level of operating performance, and firms continue to operate at a lower level for at least the next few years.

5.2. Sensitivity Analysis of the Results for the Full Sample

Because statistically significant effects of glitches on operating performance are mainly observed during the period that spans Quarter −4 through 0, we did additional sensitivity analyses to test the robustness of these results. Because the results for the three different control samples are very similar, from now on we only present the results obtained from using the most-matched control sample.

As mentioned earlier, 379 announcements of the 885 announcements convey information about other firm-specific events besides glitches. We ran separate analyses for these announcements and those announcements that only mentioned glitches and tested if the mean changes in control-adjusted operating performance are significantly different for the two subsamples. Table 7 shows that there is no difference between the mean changes of the two subsamples for all nine performance measures (two-tail p values ≥ 0.20). The median and percentage negative values across the two subsamples are also similar in magnitude. Overall, the results for the full sample are not driven by announcements that convey information about other firm-specific events besides glitches.

Table 7 Change in Control-Adjusted Operating Performance During the Year Before the Announcement for the Sample of Announcements That Only Mention Glitches and the Sample of Announcements That Also Mention Other Events

Performance measures	Announcements that mention only glitches				Announcements that also mention other events				t-value for the difference in means of two subsamples
	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.	
Percentage change in operating income	284	−105.62 (−4.65)***	−36.17 (−5.49)***	64.79 (−4.99)***	233	−109.63 (−5.10)***	−47.29 (−6.70)***	68.67 (−5.70)***	(0.13)
Percentage change in return on sales	285	−113.78 (−4.54)***	−31.36 (−6.16)***	66.67 (−5.62)***	231	−115.76 (−4.16)***	−35.52 (−6.72)***	71.00 (−6.38)***	(0.05)
Percentage change in return on assets	283	−90.33 (−4.21)***	−30.04 (−5.78)***	65.37 (−5.17)***	232	−94.58 (−4.10)***	−39.36 (−6.51)***	68.53 (−5.64)***	(0.14)
Change in the level of return on sales	465	−16.13% (−4.32)***	−3.99% (−7.34)***	65.18% (−6.55)***	356	−13.18% (−5.94)***	−3.93% (−6.99)***	66.30% (−6.15)***	(−0.68)
Change in the level of return on assets	468	−2.02% (−6.41)***	−1.39% (−6.99)***	63.25% (−5.73)***	354	−2.70% (−6.50)***	−1.32% (−6.18)***	64.69% (−5.52)***	(1.32)
Percentage change in sales	472	−5.24 (−1.56)	−0.68 (−0.63)	50.43 (−0.18)	360	−9.42 (−2.96)***	−6.45 (−3.37)***	58.62 (−3.27)***	(0.90)
Percentage change in total costs	465	9.86 (6.15)***	4.25 (7.62)***	34.84 (−6.53)***	355	11.54 (6.82)***	4.32 (6.87)***	34.93 (−5.68)***	(−0.73)
Percentage change in total assets	478	8.69 (2.41)**	4.09 (2.69)***	45.19 (−2.10)*	358	2.86 (0.81)	1.44 (1.27)	47.21 (−1.05)	(1.15)
Percentage change in total inventory	405	15.77 (3.75)***	10.80 (4.31)***	40.25 (−3.92)***	309	10.36 (1.99)*	8.25 (3.38)***	42.08 (−2.78)***	(0.81)

Notes. Results are reported for the period that begins four quarters prior to the glitch announcement (Quarter −4) and ends during the quarter of the announcement (Quarter 0). T-statistic for the mean, Wilcoxon sign rank test Z-statistic for the median, and the binomial sign test Z-statistic for the percentage negative are reported in parentheses. Percentage negative refers to the percent of sample firms whose change in performance is worse than that of their controls. The level of statistical significance from zero is noted by $^{*}p \leq 0.05$, $^{**}p \leq 0.025$, and $^{***}p \leq 0.01$ for two-tailed tests.

We also examined whether the operating performance of firms with single glitch announcements is different from firms with multiple glitch announcements. Table 8 reports that the difference in means between the single and multiple announcement subsamples is not significant (two-tail p values ≥ 0.15) for four out of the five operating income-related measures. For the change in the level of return on sales, the mean difference between single and multiple announcements is significant (p value ≤ 0.025). Of the remaining four performance metrics, only the mean difference in percentage change in total costs is significant (p value ≤ 0.01). However, the median and percentage negative values for these two subsamples for all nine metrics are very similar. Overall, the evidence does not suggest that the performance of firms with single announcements is systematically different from firms with multiple announcements. This suggests that the impact of subsequent glitches may be much less than the impact of the first glitch, indicating a diminishing negative impact of multiple glitches. It is plausible that, after experiencing the first glitch, firms may have initiated corrective actions to minimize the impact of subsequent glitches, which may be an explanation of why we do not see a significant difference in performance effects between single and multiple glitch subsamples. Examining this issue in more detail could be a future research issue.

As another sensitivity test of our results, we used the prior performance–based matched portfolio approach advocated by Barber and Lyon (1996), with annual data. We estimated the change in the level of return on sales for each sample firm by using as control the portfolio of all firms with the same two-digit SIC code as the sample firm, and with the level of return on sales in the matching year within 90% and 110% of the sample firm. Based on a sample of 851 firms, the control-adjusted mean (median) change in the level of return on sales from the year before the glitch announcements to the year of the glitch announcement is −5.51% (−1.89%), with nearly 70% of the sample firms experiencing negative changes. All these statistics are significantly different from zero (p value ≤ 0.01). The negative trend continues somewhat during the year after the glitch (mean and median changes of −2.22% and −0.01%, respectively) but not during the second year after the glitch. The results are very similar when performance is matched on return on assets. In addition, Barber and Lyon show that models that match on prior performance and SIC code are not always well specified for specific nonrandom samples (samples weighted towards extremes of size or performance, or both). To deal

Table 8 Change in Control-Adjusted Operating Performance During the Year Before the Announcement for the Sample of Single and Multiple Announcements

Performance measures	Single-glitch announcements				Multiple-glitch announcements				*t*-value for the difference in means of the single- and multiple-glitch announcement subsamples
	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.	
Percentage change in operating income	411	−108.36 (−6.22)***	−42.66 (−8.18)***	66.91 (−6.85)***	106	−97.72 (−2.49)**	−28.65 (−2.76)***	65.10 (−3.11)***	(−0.25)
Percentage change in return on sales	410	−113.13 (−5.63)***	−32.67 (−8.78)***	69.51 (−7.91)***	106	−107.54 (−2.12)*	−29.41 (−2.64)***	65.10 (−3.11)***	(−0.11)
Percentage change in return on assets	409	−90.17 (−5.51)***	−38.61 (−8.05)***	66.75 (−6.77)***	106	−97.50 (−2.22)*	−35.07 (−3.19)***	65.10 (−3.11)***	(0.16)
Change in the level of return on sales	677	−16.64% (−6.73)***	−3.93% (−9.34)***	65.88% (−8.26)***	146	−0.01% (−0.02)	−4.11% (3.95)***	64.39% (−3.48)***	(−2.54)**
Change in the level of return on assets	679	−2.47% (−8.31)***	−1.31% (−8.34)***	63.33% (−6.95)***	145	−1.62% (−3.21)***	−1.42% (−4.12)***	66.21% (−3.90)***	(−1.46)
Percentage change in sales	687	−8.66 (−3.02)***	−4.03 (−2.87)***	54.44 (−2.32)**	147	−1.26 (−0.33)	−0.98 (−0.02)	51.71 (−0.41)	(−1.54)
Percentage change in total costs	678	11.98 (8.51)***	4.26 (9.42)***	34.81 (−7.91)***	144	4.39 (1.75)	4.89 (4.09)***	33.42 (−3.98)***	(2.64)***
Percentage change in total assets	692	5.12 (1.68)	2.87 (2.15)*	47.11 (−1.52)	146	8.82 (1.87)	6.80 (2.18)*	41.10 (−2.15)*	(−0.66)
Percentage change in total inventory	578	16.72 (4.72)***	9.42 (5.37)***	40.66 (−4.49)***	136	1.85 (0.26)	10.97 (1.48)	42.65 (−1.71)	(1.87)

Notes. Results are reported for the period that begins four quarters prior to the glitch announcement (Quarter −4) and ends during the quarter of the announcement (Quarter 0). *T*-statistic for the mean, Wilcoxon sign rank test *Z*-statistic for the median, and the binomial sign test *Z*-statistic for the percentage negative are reported in parentheses. Percentage negative refers to the percent of sample firms whose change in performance is worse than that of their controls. The level of statistical significance from zero is noted by $^{*}p \leq 0.05$, $^{**}p \leq 0.025$, and $^{***}p \leq 0.01$ for two-tailed tests.

with this issue, they suggest using a size-based and prior performance–based matching that actually ignores SIC code matching. The control used under this approach is the portfolio of all firms that are within 70% to 130% in total assets of the sample firm and have the level of return on sales or assets in the matching year within 90% and 110% of the sample firm. These results are consistent with the results from the Barber and Lyon's approach that match on prior performance and SIC code, as well as the three one-to-one matched control samples.

6. Descriptive Results

To provide additional insights into the association of glitches with operating performance, we estimate the performance impacts by reasons for glitches, responsibility for glitches, by industry, size of the firm, and earlier and later glitches. The results are based on using the most-matched control sample and are for the period that spans Quarter −4 through 0, the time period that consistently shows statistically significant results. Because the sample sizes are small in some cases, more emphasis is placed on the median and percent negative results and the corresponding nonparametric tests. To keep things concise, we report results for only the five operating income metrics used in our analyses. The results for the other metrics are available on request from the authors. We report control-adjusted results obtained from using the most-matched control sample.

Table 9 reports the association of the top six reasons for glitches with operating income. These results are based on those announcements where a particular reason is the sole reason for the glitch. Thus, we exclude from our analysis the 151 multiple glitch announcements, as well as any announcements that gave multiple reasons for glitches. Parts shortages are associated with a statistically significant median change in operating income of −29.88% (p value $\leq$ 0.05), with nearly 59% of these firms experiencing a negative change in their operating income. Median changes in the other four operating income measures are also negative and significant (p values ≤ 0.025).

The importance of rapid ramping and rollout of new products and processes is underscored by the fact that poor performance on these dimensions is negatively associated with operating income. Table 9 shows that ramping and rollout problems are associated with a median drop in operating income of nearly 50% (p value ≤ 0.01), with nearly 76% of the firms experiencing a negative change (p value ≤ 0.01). The other four operating income measures also indicate negative and significant changes in performance (p values ≤ 0.025).

Table 9 shows that glitches due to order changes are associated with a median change in operating income of about −84% (p value ≤ 0.01), with nearly 74% of

Table 9 Change in Control-Adjusted Operating Performance of Sample Firms During the Year Before the Announcement of Glitches by Different Reasons for Glitches Using the Most-Matched Control Sample

Performance measures	Part shortage				Ramping and rollout problems				Order changes by customers			
	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.
Percentage change in operating income	63	−73.06 (−2.61)**	−29.88 (−2.21)*	58.63 (−1.37)	46	−924.09 (−1.36)	−50.00 (−3.65)***	76.09 (−3.53)***	34	−200.57 (−2.12)*	−84.15 (−3.03)***	73.53 (−2.74)***
Percentage change in return on sales	63	−75.58 (−2.89)**	−21.57 (−2.39)**	60.32 (−1.63)	47	−1,547.11 (−1.47)	−25.08 (−4.19)***	78.83 (−3.95)***	34	−183.52 (−2.15)*	−64.24 (−3.21)***	73.53 (−2.74)***
Percentage change in return on assets	63	−68.50 (−2.92)***	−20.64 (−2.58)**	61.91 (−1.89)	45	−688.15 (−1.10)	−38.76 (−3.30)***	68.89 (−2.53)**	32	−227.70 (−2.16)*	−52.07 (−3.41)***	71.88 (−2.48)**
Change in the level of return on sales	106	−30.61% (−1.60)	−1.05% (−2.13)**	56.41% (−1.32)	67	−26.76% (−2.30)**	−4.08% (−4.55)***	77.62% (−4.52)***	51	−24.44% (−2.45)**	−6.78% (−3.66)***	68.67% (−2.67)***
Change in the level of return on assets	104	−2.28% (−2.79)***	−0.75% (−2.28)**	57.70% (−1.57)	66	−2.19% (−2.84)***	−1.37% (−3.40)***	69.70% (−3.20)***	52	−5.37% (−2.90)***	−3.03% (−3.57)***	70.24% (−2.92)***

Performance measures	Production problems				Development and engineering changes				Quality problems			
	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.
Percentage change in operating income	25	−292.27 (−1.46)	−59.22 (−2.42)**	68.00 (−1.80)	17	−61.92 (−0.84)	−92.38 (−1.56)	76.48 (−2.18)*	12	−56.05 (−1.62)	−10.03 (−0.98)	50.00 (0.00)
Percentage change in return on sales	25	−210.21 (−1.50)	−43.00 (−2.50)**	76.00 (−2.60)***	17	−65.93 (−1.13)	−96.13 (−1.70)	76.48 (−2.18)*	12	−38.03 (−1.49)	−32.75 (−1.22)	66.67 (−1.15)
Percentage change in return on assets	26	−295.77 (−1.42)	−62.27 (−2.39)**	69.24 (−1.96)*	17	−60.48 (−1.03)	−90.19 (−1.75)	76.48 (−2.18)*	12	−35.76 (−1.56)	−16.88 (−1.29)	66.67 (−1.15)
Change in the level of return on sales	42	7.55% (0.50)	−1.95% (−1.29)	59.53% (−1.24)	30	−59.22% (−1.32)	−6.92% (−2.12)*	66.67% (−1.83)	20	−56.58% (−1.07)	−2.42% (−0.92)	60.00% (−0.89)
Change in the level of return on assets	44	−1.01% (−1.04)	−0.98% (−1.33)	61.37% (−1.51)**	30	−3.18% (−2.10)*	−1.19% (−2.16)*	63.37% (−1.46)	20	−0.80% (−0.52)	−0.13% (−0.35)	50.00% (0.00)

Notes. Results are reported for the period that begins four quarters prior to the glitch announcement (Quarter −4) and ends during the quarter of the announcement (Quarter 0). *T*-statistic for the mean, Wilcoxon sign rank test *Z*-statistic for the median, and the binomial sign test *Z*-statistic for the percentage negative are reported in parentheses. Percentage negative refers to the percent of sample firms whose change in performance is worse than that of their controls. The level of statistical significance from zero is noted by $^{*}p \leq 0.05$, $^{**}p \leq 0.025$, and $^{***}p \leq 0.01$ for two-tailed tests.

the firms experiencing a negative change (p value $\leq$ 0.01). 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.

Finally, although glitches due to production problems; development and engineering problems; and quality problems are also negatively associated with operating income, results for these reasons should be interpreted cautiously, because the results are based on fairly small sample sizes.

Table 10 reports the association of glitches with operating performance when internal sources, suppliers, and customers are solely responsible for the glitches. Internal glitches are associated with a median decrease in operating income of 55.12% (p value $\leq$ 0.01), with nearly 68% of the firms experiencing negative performance (p value $\leq$ 0.01). Glitches due to suppliers are associated with a median decrease in operating income of 31.28% (p value $\leq$ 0.01), with nearly 61.12% of the firms experiencing negative performance. Customer-caused glitches are associated with a median decrease in operating income of 57.73% (p value $\leq$ 0.01), with nearly 70% of such firms experiencing negative performance (p value $\leq$ 0.01). The negative and significant association with operating income is also generally observed for the other four operating income metrics. The results show the heavy price one link of the supply chain pays for the poor performance by other links in the supply chain.

Table 11 presents results for the following six broadly defined industry groups, those with at least 30 observations:

- Natural resources—primary SIC code between 0001–1999.
- Process—primary SIC code between 2000–2999.
- High technology—primary SIC code between 3570–3579, 3660–3699, or 3760–3789.
- Transportation—primary SIC Code between 3700–3759 or 3790–3799.
- Wholesale and retailing—primary SIC code between 5000–5999.
- Services—primary SIC between 6000–6999.

The results indicate that the association between glitches and operating income is negative across all six industry groups. The median percent changes in operating income for all industry groups are negative and most are significant at the 10% level in two-tailed

Table 10 Change in Control-Adjusted Operating Performance of Sample Firms During the Year Before the Announcement of Glitches by Different Sources of Responsibility for Glitches Using the Most-Matched Control Sample

Performance measures	Internal				Supplier				Customers			
	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.
Percentage change in operating income	135	−193.57 (−2.72)***	−55.12 (−5.38)***	68.15 (−4.22)***	54	−111.90 (−3.39)***	−31.28 (−2.84)***	61.12 (−1.63)	62	−104.92 (−3.14)***	−57.73 (−3.70)***	70.97 (−3.30)***
Percentage change in return on sales	136	−316.22 (−1.50)	−42.01 (−6.04)***	72.06 (−5.14)***	54	−105.58 (−3.31)***	−23.90 (−2.79)***	64.88 (−2.19)*	62	−102.31 (−3.63)***	−39.42 (−3.85)***	72.59 (−3.55)***
Percentage change in return on assets	135	−122.21 (−2.76)***	−41.79 (−5.49)***	70.37 (−4.73)***	53	−94.85 (−3.38)***	−23.11 (−3.10)***	66.06 (−2.34)**	61	−103.42 (−3.30)***	−46.06 (−3.72)***	65.52 (−2.42)**
Change in the level of return on sales	237	−14.41% (−2.89)***	−3.91% (−5.50)***	67.09% (−5.26)***	92	−39.80% (−1.64)	−0.86% (−1.67)	55.44% (−1.04)	94	−27.20% (−2.92)***	−6.44% (−4.73)***	67.03% (−3.30)***
Change in the level of return on assets	239	−2.30% (−4.80)***	−1.44% (−5.10)***	66.19% (−5.01)***	89	−1.98% (−2.45)**	−0.30% (1.74)	53.93% (−0.74)	95	−4.33% (−3.87)***	−2.39% (−4.36)***	66.32% (−3.81)***

Notes. Results are reported for the period that begins four quarters prior to the glitch announcement (Quarter −4) and ends during the quarter of the announcement (Quarter 0). *T*-statistic for the mean, Wilcoxon sign rank test *Z*-statistic for the median, and the binomial sign test *Z*-statistic for the percentage negative are reported in parentheses. Percentage negative refers to the percent of sample firms whose change in performance is worse than that of their controls. The level of statistical significance from zero is noted by $^{*}p \leq 0.05$, $^{**}p \leq 0.025$, and $^{***}p \leq 0.01$ for two-tailed tests.

tests. All industry groups show a significant decrease in the median changes in the level of return on sales and assets (p value ≤ 0.025). Although not reported in Table 11, two of the six industry groups show a significant decrease in the median percent changes in sales (p value ≤ 0.05), and all industry groups show a significant increase in median percent changes in total costs (p value ≤ 0.025).

Hendricks and Singhal (2003) argue that the association of glitches with operating performance is

Table 11 Change in Control-Adjusted Operating Performance of Sample Firms During the Year Before the Announcement of Glitches by Different Industries Using the Most-Matched Control Sample

Performance measures	Natural resources				Process				High technology			
	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.
Percentage change in operating income	21	−357.00 (−0.82)	−58.96 (−1.70)	72.19 (−2.41)**	61	−112.29 (−4.72)***	−55.57 (−4.84)***	77.05 (−4.22)***	151	−132.72 (−4.17)***	−56.65 (−5.01)***	67.55 (−4.31)***
Percentage change in return on sales	21	−189.41 (−0.95)	−31.36 (−1.77)	71.43 (−1.96)*	62	−94.94 (−5.24)***	−42.09 (−5.18)***	79.04 (−4.57)***	151	−169.41 (−3.91)***	−46.83 (−5.26)***	68.22 (−4.48)***
Percentage change in return on assets	20	−1.83 (−0.01)	−43.03 (−1.54)	75.00 (−2.23)*	61	−81.98 (−4.55)***	−47.84 (−4.36)***	75.41 (−3.96)***	151	−126.45 (−3.48)***	−39.09 (−5.06)***	66.89 (−4.15)***
Change in the level of return on sales	34	−59.47% (−1.18)	−9.59% (−2.80)***	72.48% (−3.09)***	91	−9.18% (−2.29)**	−5.07% (−4.09)***	72.53% (−4.29)***	261	−12.88% (−3.25)***	−5.67% (−6.03)***	66.29% (−5.26)***
Change in the level of return on assets	34	−2.94% (−1.31)	−2.45% (−3.03)***	72.48% (−3.09)***	91	−1.52% (−2.32)**	−1.27% (−2.87)***	68.14% (−3.47)***	261	−2.68% (−5.34)***	−1.80% (−5.66)***	64.37% (−4.64)***

Performance measures	Transportation				Wholesale and retailing				Services			
	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.
Percentage change in operating income	93	−65.69 (−2.48)**	−32.55 (−3.00)***	64.52 (−2.80)***	53	−24.24 (−1.08)	−5.47 (−1.07)	52.83 (−0.33)	52	−96.87 (−1.99)**	−70.33 (−2.05)**	59.62 (−1.39)
Percentage change in return on sales	93	−60.92 (−2.02)*	−24.86 (−2.75)***	64.52 (−2.80)***	53	−29.27 (−1.30)	−25.17 (−2.13)*	62.27 (−2.29)**	51	−122.94 (−2.53)**	−58.60 (−3.06)***	66.67 (−2.38)**
Percentage change in return on assets	93	−43.78 (−1.70)	−19.72 (−2.61)***	65.60 (−3.01)***	53	−28.09 (−1.40)	−17.28 (−2.01)*	59.50 (−1.38)	51	−90.63 (−1.91)	−51.12 (−0.28)*	64.71 (−2.10)*
Change in the level of return on sales	140	−29.41% (−1.78)	−1.79% (−2.60)**	62.15% (−2.87)***	76	−5.56% (−2.62)**	−1.57% (−2.55)**	60.53% (−1.84)	96	−37.92% (−3.89)***	−11.27% (−5.34)***	69.75% (−3.88)***
Change in the level of return on assets	141	−1.84% (−3.09)***	−0.54% (−2.87)***	58.16% (−1.94)	76	−1.99% (−2.79)***	−0.66% (−2.48)**	61.84% (−2.09)*	97	−5.42% (−3.52)***	−2.39% (−4.01)***	68.05% (−3.55)***

Notes. Results are reported for the period that begins four quarters prior to the glitch announcement (Quarter −4) and ends during the quarter of the announcement (Quarter 0). *T*-statistic for the mean, Wilcoxon sign rank test *Z*-statistic for the median, and the binomial sign test *Z*-statistic for the percentage negative are reported in parentheses. Percentage negative refers to the percent of sample firms whose change in performance is worse than that of their controls. The level of statistical significance from zero is noted by $^{*}p \leq 0.05$, $^{**}p \leq 0.025$, and $^{***}p \leq 0.01$ for two-tailed tests.

more severe for smaller firms than for larger firms, 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. Small firms may take longer to recover from glitches because their small size reduces their power and clout to influence and change the behavior of other supply chain partners to speed recovery. We test this hypothesis with operating income–based measures. Smaller (larger) firms are those that have total assets below (above) \$77.9 million, the median total assets of the full sample in Quarter −1. Table 12 indicates that supply chain glitches are negatively associated with operating income for both smaller and larger firms. Furthermore, the magnitude of association is more negative for smaller firms when compared with larger firms. The mean percent change in operating income of −150.55% for smaller firms is significantly different from −85.65% for larger firms (p value ≤ 0.10). The mean changes in the level of return on sales and level of return on assets for smaller firms are also significantly more negative than that of larger firms (p value ≤ 0.01).

Hendricks and Singhal (2003) argue that the association of earlier (in terms of calendar date) glitches with operating performance will be less negative than the more recent glitches, primarily because of the global competitive and hypercompetitive environments that most firms have faced in recent years. We test this hypothesis (see the results in the lower half of Table 12), classifying glitches in 1996 and before as earlier glitches and the rest as later glitches. The results indicate that the impact for earlier glitches is no different from later glitches (all p values ≥ 0.15).

7. Summary and Future Research Directions

Based on a sample of 885 supply chain glitches announced by publicly traded firms, we estimate the association of glitches with operating performance. Changes in various operating performance metrics for the sample firms are compared against a sample of control firms of similar size and from similar industries. After adjusting for the performance of the controls, we find that in the year leading to the announcement glitches on average are associated

Table 12 Change in Control-Adjusted Operating Performance of Sample Firms During the Year Before the Announcement of Glitches for Smaller and Larger Firms and Earlier and Later Glitches Using the Most-Matched Control Sample

	Larger firms				Smaller firms				t-value for the difference in means of larger and smaller firms
Performance measures	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.	
Percentage change in operating income	324	−85.65 (−3.97)***	−29.48 (−5.76)***	65.13 (−5.44)***	193	−150.55 (−5.06)***	−86.39 (−6.41)***	68.92 (−5.26)***	(1.76)
Percentage change in return on sales	323	−72.48 (−4.12)***	−25.23 (−6.20)***	67.81 (−6.29)***	193	−178.07 (−4.32)***	−72.43 (−6.70)***	69.95 (−5.54)***	(2.36)**
Percentage change in return on assets	323	−66.01 (−4.20)***	−22.90 (−5.89)***	65.02 (−5.40)***	192	−132.95 (−4.01)***	−66.18 (−6.30)***	69.80 (−5.49)***	(1.82)
Change in the level of return on sales	414	−4.25% (−3.41)***	−2.34% (−6.62)***	65.46% (−6.29)***	409	−25.74% (−5.28)***	−7.24% (−7.93)***	65.77% (−6.38)***	(4.27)***
Change in the level of return on assets	414	−1.44% (−6.01)***	−0.81% (−6.50)***	64.26% (−5.80)***	410	−3.25% (−6.95)***	−2.23% (−6.81)***	63.42% (−5.43)***	(3.45)***
	Early disruptions (1996 and before)				Later disruptions (1997 and after)				t-value for the difference in means of early and later disruptions
Performance measures	Obs.	Mean	Median	% neg.	Obs.	Mean	Median	% neg.	
Percentage change in operating income	283	−96.07 (−5.93)***	−37.47 (−6.56)***	66.79 (−5.65)***	234	−235.80 (−1.76)	−47.60 (−5.40)***	66.24 (−4.97)***	(1.04)
Percentage change in return on sales	281	−100.30 (−5.14)***	−32.09 (−7.01)***	69.75 (−6.62)***	235	−226.30 (−1.81)	−31.95 (−5.78)***	−5.44 (−6.38)***	(1.00)
Percentage change in return on assets	282	−81.65 (−5.40)***	−38.35 (−6.97)***	68.44 (−6.19)***	233	−220.60 (−1.78)	−34.12 (−5.22)***	64.82 (−4.52)***	(1.11)
Change in the level of return on sales	433	−11.98% (−4.83)***	−3.93% (−7.72)***	65.17% (−6.31)***	390	−16.33% (−4.95)***	−3.99% (−6.57)***	66.16% (−6.38)***	(1.05)
Change in the level of return on assets	435	−2.66% (−7.34)***	−1.44% (−7.65)***	65.52% (−6.47)***	389	−1.92% (−5.29)***	−1.08% (−5.43)***	61.96% (−4.72)***	(−1.44)

Notes. Results are reported for the period that begins four quarters prior to the glitch announcement (Quarter −4) and ends during the quarter of the announcement (Quarter 0). T-statistic for the mean, Wilcoxon sign rank test Z-statistic for the median, and the binomial sign test Z-statistic for the percentage negative are reported in parentheses. Percentage negative refers to the percent of sample firms whose change in performance is worse than that of their controls. The level of statistical significance from zero is noted by $^{*}p \leq 0.05$, $^{**}p \leq 0.025$, and $^{***}p \leq 0.01$ for two-tailed tests.

with a 107% drop in operating income, 114% drop in return on sales, and 93% drop in return on assets. During this period the level of return on sales (return on assets) drops by 13.78% (2.32%). Glitches are also associated with an average of 6.92% lower sales growth, 10.66% growth in cost, 6.08% growth in assets, and 13.88% growth in inventories. Furthermore, firms do not quickly recover from the negative consequences of glitches. During the two-year period after the glitch announcement, the changes in operating income, sales, total costs, and inventories are insignificantly different from zero.

Our results are consistent with Hendricks and Singhal's (2003, 2005) studies on the stock market reaction to supply chain glitches. They find that such announcements are associated with statistically significant decreases in stock prices. We find statistically significant negative association of glitches with operating performance. This supports and strengthens the stock market reaction documented by Hendricks and Singhal, in the sense that the market is reacting to the actual and anticipated drop in profitability due to glitches and not just some overreaction to "bad news" or "market overexuberance."

The dependency of this study on secondary data and publicly available information is not without limitations. One limitation is that the glitch may occur in a specific business unit of a firm but our analyses are based on the performance of the firm as a whole because historical and detailed information about business units is not easily available. This is a limitation of most studies that use secondary data. There is no reason to believe that this limitation introduces a systematic bias in our analyses, given that our sample points are distributed across time, industry, and size, and that our sample is quite large. Furthermore, this limitation should be less of a concern for smaller firms because these firms are likely to focus on a single business. The results for the smaller firms show strong negative association between glitches and operating performance. Nonetheless, future research that addresses this limitation should be useful.

As one would expect, the details about glitches revealed in public announcements are often sparse. This prevents us from identifying and doing detailed analysis of the underlying causes of glitches. For example, many have argued that organizational changes such as integrated planning across various functions, collaboration and information sharing with other partners in the supply chain, and investments in technologies such as ERP and SCM can help reduce the frequency and intensity of glitches (Cachon and Fisher 2000, Flynn and Flynn 1999, Lee et al. 1997, Lewis and Talalayevsky 1997). We do not have information on the extent to which the lack of these or other organization practices and investments are causing the glitches. Recent research has used surveys to measure the existence and intensity of these practices (see, for example, Rosenzweig et al. 2003, Frohlich and Westbrook 2001). However, performance information collected through surveys is not always as reliable and objective as secondary data. Use of surveys to collect information on practices together with secondary data on performance could be a valuable synthesis of the two different approaches of linking supply chain management issues to corporate performance.

Although we have used currently recommended approaches in the literature for generating controls, no matching process is perfect, particularly when a large number of firms are to be matched on multiple criteria. It is still possible that some unknown idiosyncrasies in the selection of control firms may be driving our results. Experimentation with alternate ways of measuring glitches, alternate methodologies, and use of different data sources could clarify the robustness of the results of this paper.

Another limitation of our study is that we focus on the association of glitches with operating performance of the announcing firms. It is easy to visualize that the announcing firm's supplier and customer could also be negatively impacted. Estimating the impact on upstream and downstream supply chain partners could be an interesting subject of future research, because it would document the total economic impact of glitches on the extended supply chain and provide even stronger incentives to the various supply chain partners to work collaboratively and cooperatively. It would also be useful to study the effect of glitches on competitors.

Given the serious economic consequences of supply chain glitches, firms must make every effort to avoid glitches. Although good supply chain management practices can prevent glitches, firms also need to develop the capability to predict glitches. This involves selecting and tracking leading indicators of glitches. Research that can identify these leading indicators from historical data and link it to glitches could be particularly useful in providing early warning signals about possible glitches.

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