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Bullwhip Effect in Supply Chains and Cost Rigidity

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Abstract: The bullwhip effect is the phenomenon of distorted information that causes the amplification of variability of demand in supply chains. We examine the relationship between the bullwhip effect and cost behavior using a large sample of U.S. public firms from 1980 to 2019. Our empirical results show that the costs of firms with a higher intensity of bullwhip effect are significantly more responsive to changes in sales, suggesting that firms facing higher amplification of demand will adopt a less rigid short-term cost structure with lower fixed and higher variable costs. Furthermore, the bullwhip effect is associated with a higher elasticity of number of employees, operating leases, and rental expenses with respect to sales. The findings of mediation analyses suggest that firms are likely to lease capacity resources to increase the flexibility and manage the operating risk associated with the bullwhip effect. The results are robust to alternative model specifications. This study contributes to both the cost accounting and supply chain management literature, and documents large sample evidence on whether and how the bullwhip effect affects a firm's choice of cost structure.

Keywords: bullwhip effect; cost rigidity; cost management; supply chain

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1. Introduction

The shortages and disruptions in global supply chains during the COVID-19 Pandemic have affected people's daily life and attracted wide public attention. In a recent Wall Street Journal article, Stank et al. (2021) attribute the great supply shortages to the pitfall of the bullwhip effect, "As pandemic related to COVID-19 evolves, traditional supply-and-demand patterns around the world is disrupted. Due to the dissemination of pandemic relief checks and vaccinations, pent-up demand drives a sharp pick-up in demand and resulting consumer spending spike, which trigger shortages of many products. Thus, many firms face uncertainty surrounding the demand predictions and are advised to be cautious not to rapidly expand the manufacturing capacity to avoid the pitfall of the bullwhip effect".[1]

The bullwhip effect is a well-known economic phenomenon whereby demand variability tends to amplify moving upstream in a supply chain due to information distortion (Lee et al., 1997a; Bray & Mendelson, 2012; Wang & Disney, 2016). The operating risk caused by the bullwhip effect will inevitably affect managers' deliberate resource commitment decisions, as Banker et al. (2018) suggest, "There is a large analytical literature on various supply chain issues in the operations management research. One of the key topics in this literature is the bullwhip effect . . . This research does not consider resource adjustment costs and how they interact with bullwhip-related variability, while the cost management

research does not consider the downstream-upstream interactions that cause the bullwhip effect, suggesting opportunities for new insights in both areas".

Cost behavior analysis is an essential element in cost management practice, and often provides valuable insights for an organization's performance. The modern cost accounting literature provides rich evidence that cost behavior can be systematically affected by management's deliberate decisions on resource commitments (M. A. Anderson et al., 2003; Banker & Byzalov, 2014). Recognizing the importance of cost behavior, S. W. Anderson (2007) indicates that managers should comprehend the full value chain and all stakeholders to build a cost structure that ensures long-run sustainable profits and calls for more research to advance our knowledge about structural cost management. Extant cost management studies have investigated the economic determinants of cost structures and documented mixed results. For instance, Banker et al. (2014) present both analytical and empirical evidence that firms with more uncertain demand will choose a more rigid short-run cost structure. In contrast, Kallapur and Eldenburg (2005) argue that real-options theory predicts technologies involving low fixed and high variable costs are preferable when uncertainty increases. Accordingly, Washington State hospitals reduced the rigidity of their costs after Medicare introduced the prospective payment system that could increase revenue uncertainty. Similarly, Holzhacker et al. (2015a) show that firms with greater demand uncertainty and financial risk are likely to alter resource procurement choices related to outsourcing, leasing equipment, and hiring contract labor to increase cost elasticity. Meanwhile, a change to fixed-price regulation imposes cost pressures and operating risks. For-profit organizations will choose a less rigid cost structure to increase cost elasticity and reduce cost asymmetry in responding to such a regulatory change (Holzhacker et al., 2015b).

In this study, we examine whether and how the firm-level bullwhip effect affects a firm's choice of cost structure and its investment in production technology. On one hand, it would be optimal for firms with higher demand uncertainty to have a more rigid short-term cost structure to reduce congestion costs when facing an unusual high realization of demand (Banker et al., 2014). On the other hand, firms with a higher intensity of the bullwhip effect could incur substantial costs due to excess inventory and inefficient capacity utilization. Thus, such firms are likely to lower the adjustment costs and invest in technologies involving a scalable cost structure with fewer fixed costs. Using a panel of US companies during 1980–2019, we find that, after controlling for economic determinants of cost structure, the interaction term between the intensity of the bullwhip effect and the log change in sales is significantly positively associated with the log changes in selling, general and administrative cost (SG&A), cost of goods sold (COGS), number of employees, operating leases, and rental expenses at the 1 percent significance level. The relationship between the bullwhip effect and cost rigidity is also economically significant. For example, from the lower quartile to the upper quartile of the bullwhip effect, the percentage change in costs for a 1 percent change in sales is substantially stronger: an increase of 19 percent for SG&A costs, an increase of 1 percent for COGS, and an increase of 18 percent for the number of employees. These results suggest to managers that firms respond to the bullwhip effect by adopting a flexible cost structure as a means of mitigating the heightened operating risk it creates.

Overall, our results suggest that a company with higher amplification of demand variability is likely to adopt a less rigid cost structure with increased reliance on variable costs. Such a scalable cost structure enables companies to adjust their costs rapidly in response to changes in sales to mitigate the operating risk caused by the bullwhip effect in supply chains. Importantly, the regression results for employees, operating leases, and rental expenses imply that firms would hire more contract employees and lease more capacity resources to lower adjustment costs in the presence of the bullwhip effect. This is

consistent with the evidence that California hospitals facing higher demand uncertainty and financial risk increased the share of contract labor and the leasing of equipment for a more flexible cost structure (Holzhacker et al., 2015a). Our results are robust when raw measures of the bullwhip effect are used and when firm fixed effects and Fama–Macbeth regressions are estimated. In addition, our results are consistent after accounting for long-term structural shifts in cost behavior, which are captured by cost stickiness and capacity utilization.

Our study contributes to the literature in several ways. First, current operations management research overlooks resource adjustment costs and their interaction with the bullwhip effect, while the existing cost management literature does not address the implications of interactions among supply chain players associated with the bullwhip effect. Against this backdrop, Banker et al. (2018) propose research linking the bullwhip effect and cost management as a future research area. This study fills this gap in both the cost management literature and supply chain literature and provides additional evidence on how the operating risk associated with the bullwhip effect affects the cost behavior of firms. The main difference between demand uncertainty and the bullwhip effect is that the bullwhip effect refers to the amplification of demand variability along the supply chain, caused by managers' endogenous responses to distorted demand information. Although the exogenous demand uncertainty increases cost rigidity (Banker et al., 2014), our results suggest that firms facing higher bullwhip-related demand variability are likely to adopt a more scalable cost structure and make resource procurement choices to lower the adjustment costs, consistent with the findings in prior literature (Balakrishnan et al., 2008; Kallapur & Eldenburg, 2005; Holzhacker et al., 2015a). Second, our study expands the extant research on the determinants of cost structure and operating leverage (e.g., Kallapur & Eldenburg, 2005; Banker et al., 2014; Holzhacker et al., 2015b; Aboody et al., 2018), which can advance our knowledge about structural cost management (S. W. Anderson, 2007; Krishnan, 2015). Managers benefit from our findings, as the bullwhip effect can be an important factor to consider in their cost management and operating risk decisions.

The remainder of the paper is organized as follows. Section 2 reviews the extant supply chain and cost accounting literature and develops the theoretical hypotheses on the relationship between the bullwhip effect and cost rigidity. Section 3 presents the research design and describes the research sample. Section 4 reports the principal empirical results and additional analyses. Section 5 summarizes the main findings and concludes.

2. Literature Review and Hypothesis Development

2.1. Supply Chain and Bullwhip Effect

The bullwhip effect is the supply chain phenomenon whereby the variability of demand amplifies from a downstream buyer to an upstream supplier (Lee et al., 1997a, 1997b; Cachon et al., 2007). At the firm level, the bullwhip effect exists when a company's purchase orders and production are more volatile than its customer orders (Bray & Mendelson, 2012). The bullwhip effect can lead to enormous supply chain inefficiencies, mismatches between demand and production, excessive inventory/backlog, poor customer service, and misguided capital investments (Lee et al., 1997a). In his seminal book, Forrester (1961) studied the effect of variance amplification using an "industrial dynamics" approach and developed the role-playing Beer Distribution Game to simulate the decision-making behavior in supply chains. In the 1990s, Procter & Gamble (P&G) found that variabilities in demand orders for its product, Pampers, increased as they moved up the supply chain, though diapers were consumed at a steady rate (Lee et al., 1997a). P&G first named such a phenomenon of variability amplification the "Bullwhip" effect (Wang & Disney, 2016). Sterman (1989) conducted experiments with the Beer Distribution Game to study human

behavior in inventory management, and the experimental results showed that the bullwhip effect can be attributed to players' systematic irrational behavior, such as misperceptions of inventory and demand information. Lee et al. (1997b) suggest that the bullwhip effect can be an inevitable result of the players' rational behavior within the supply chain's infrastructure. They consider a series of companies in a supply chain, and each company orders from its immediate upstream member. They identify an additional four causes of the bullwhip effect: demand signal processing, the rationing game, order batching, and price variations. Demand signal processing represents situations where demand is non-stationary and past demand information is used to predict future demand. The rationing game refers to the strategic behavior of buyers to order more units than actual needs when potential supply shortages are anticipated. Batching of orders can occur when there is a nonzero fixed order cost, and it is not economical to order in every period. Price variations mean that the purchase prices of a product fluctuate over time.

A large body of literature has illustrated the existence of the bullwhip effect in a variety of supply chains, such as TV sets (Holt et al., 1968), soup (Lee et al., 1997a), pasta (Hammond, 1994), salads and chilled prepared meals (Fransoo & Wouters, 2000), machine tools (E. Anderson et al., 2000), semiconductor (Terwiesch et al., 2005), groceries (Lai, 2005), and toys (Wong et al., 2007). To address the external validity issue of single-firm or single-industry studies, Cachon et al. (2007) investigate the strength of the bullwhip effect in a wide panel of US industries and find that while the bullwhip effect exists in wholesale and some manufacturing industries, the effect is not widespread in the U.S. economy. They further indicate the possibility that "firms exhibit the bullwhip effect but the industry does not", and call for more research to probe the bullwhip effect at the firm level. Accordingly, Bray and Mendelson (2012) study the bullwhip effect in a panel of 4689 public US firms and find that the effect largely prevails in firm-level data. When seasonality is removed, 30 out of 31 industries show a positive mean bullwhip effect, and 26 industries exhibit it when seasonality exists. Overall, about two-thirds of US firms bullwhip, and the mean quarterly standard deviation of upstream orders exceeds that of demand by USD 20 million. Similarly, Shan et al. (2014) examine the bullwhip effect using a sample of over 1200 Chinese companies listed on the Shanghai and Shenzhen stock exchanges during 2002–2009, and document that more than two-thirds of the companies in their sample exhibit the bullwhip effect.

2.2. Cost Management and Cost Rigidity

The traditional view of cost behavior assumes that costs mechanistically change in relation to a change in activity levels, and managers do not play an explicit role in such a functional relation. The recent cost management research documents that cost behavior can be moderated by various deliberate management decisions on resource commitments subject to context-specific constraints, incentives, and biases (Banker et al., 2018). To achieve competitive advantage and earn sustainable long-term profits, managers must comprehend the full value chain and employ the tools of organizational, product, and process design to build a cost structure that is aligned with business strategy (S. W. Anderson, 2007). One traditional wisdom on cost structure in accounting textbooks is that firms with higher fixed costs and lower variable costs are exposed to a higher operating risk and are more likely to suffer a loss when sales decline (e.g., Horngren et al., 2012; Krishnan, 2015; Garrison et al., 2017). In contrast, firms with lower operating leverage have more flexibility because of fewer upfront resource commitments, and as a result, these firms, when confronting fluctuating and uncertain demand conditions, will opt for a more flexible cost structure (Balakrishnan et al., 2008).

Cost accounting research has documented a variety of economic and institutional factors that affect management decisions on cost structure. Kallapur and Eldenburg (2005) apply the real-options theory of investment to explain the effect of uncertainty on cost structure. They argue that uncertainty drives firms to adopt technologies with greater variable costs as the value of flexibility increases in an uncertain environment. Supporting this theoretical prediction, they find that hospitals in Washington state significantly increased the ratio of variable to total costs after a Medicare change in reimbursement that increased the revenue uncertainty for hospitals. Similarly, Holzhacker et al. (2015b) posit that a switch to fixed-price regulation increases cost pressures and the operating risk of an organization because its revenues are decoupled from the costs. In response, they find that for-profit hospitals chose a less rigid cost structure to increase cost elasticity and reduce cost asymmetry after the change to fixed-price regulation in Germany. In another study, Holzhacker et al. (2015a) argue that firms with greater demand uncertainty and financial risk are likely to alter resource procurement choices related to outsourcing, leasing equipment, and hiring contract labor to increase cost elasticity. Their empirical results, based on 2022 hospital-year observations, support these theoretical predictions. Aboody et al. (2018) find that managers substituted fixed costs with variable costs in response to reductions in option-based compensation following the issuance of FAS 123(R) and conclude that reductions in risk-taking incentives motivated managers to lower operating leverage and choose a more flexible cost structure in order to avoid the downside potentials of earnings. Banker et al. (2014) argue that greater uncertainty in demand increases the probability of unusually large demand spikes. Consequently, firms will make more capacity investments up front to reduce congestion costs as uncertainty in demand rises, resulting in a less flexible cost structure. Irvine et al. (2016) find that higher customer-base concentration will lead to more customer-specific investments, resulting in larger fixed costs for suppliers. Chang et al. (2021) further document that the positive relationship between cost rigidity and customer-base concentration can be intensified by suppliers' market competition. Recently, Fang et al. (2023) showed that the availability of a credit default swap (CDS) increased creditors' liquidation incentives to push borrowers over bankruptcy in the event of default, and consequently, borrowers increased the elasticity of their cost structure after the inception of CDS trading.

2.3. Hypotheses Development

In supply chains, the distortion of demand information tends to increase as the information is transferred in the form of orders from downstream to upstream, and thus misguide upstream members in the formulation of their production and inventory decisions (Lee et al., 1997b). The information distortion can be an outcome of managers' irrational behavior, "misperceptions of feedback" (Sterman, 1989), or be caused by rational strategic interactions among managers. For instance, when a buyer is anticipating a shortage in supply and that its supplier may ration supply of the product, the buyer will rationally place an order larger than its actual need to secure more units. However, the buyer may cancel excess orders once the supply shortage begins to ease and the buyer has stockpiled enough of the units it needs. This phenomenon of phantom orders has been documented in the prior supply chain literature (Sterman & Dogan, 2015; Chang et al., 2018). If the past demand information is used to update the forecasts, managers of the supplier would interpret a surge in demand as a signal of higher future demand and ramp up production or place a larger purchase order for a higher sales forecast in the subsequent period, leading to an oversupply in the market.

The information distortion will be further aggravated if different buyer orders are positively correlated or if there is a long lead time in replenishing orders. In an extreme

scenario, buyers would place orders for multiple periods in the same period. An unusually high realization of demand in the current period would imply lower realizations in the subsequent periods. Therefore, the bullwhip effect can have serious implications for a firm's structural cost management. The amplification of demand variability can lead to a tremendous mismatch between demand and supply. Firms could incur substantial costs due to excess inventory and inefficient capacity utilization and suffer a huge loss when the mismatch occurs. To mitigate such a downside operating risk, it is critical for firms to lower the adjustment costs and invest in the technologies involving a flexible cost structure when the bullwhip effect prevails. This theoretical prediction warrants our empirical investigation. Our research hypothesis is presented as an alternative form, as follows:

Hypothesis 1 (H1). *Firms affected by the bullwhip effect are likely to adopt a flexible cost structure.*

When facing increases in downside risk, firms will take actions to reduce the rigidity of their cost structure and mitigate the potential of huge losses. Purchasing assets requires upfront long-term resource commitments and would lead to large irreversible sunk costs if the realizations of market demand are low. In contrast, leasing and renting assets allow firms to expand their current production or service capacity when sales increase, without incurring the substantial upfront costs. Prior studies document that firms opt for leasing assets to reduce the variance in earnings or operating cash flows (Liebowitz, 1983; Smith & Wakeman, 1985). Organizations with higher uncertainty and financial risk are more likely to lease equipment to increase cost elasticity and manage the risk associated with cost structures (Holzhacker et al., 2015a).

Firms with a higher intensity of the bullwhip effect need to ramp up or scale down production efficiently due to the amplification of demand variability. Because the adjustment costs of leasing or renting are much lower than those from purchasing equipment, firms are likely to lease and rent capacity resources to achieve a more flexible cost structure when they face higher bullwhip-related variability. This leads to the second research hypothesis, presented below as an alternative form:

Hypothesis 2 (H2). *Firms affected by the bullwhip effect are likely to reduce the rigidity of their cost structure by increasing leasing and renting relative to purchasing of long-lived assets.*

3. Empirical Model and Research Sample

3.1. Empirical Model

Our empirical model is specified as follows:

$$\begin{aligned}\Delta\ln COST_{it} = {} & \beta_0 + \beta_1\,\Delta\ln SALE_{it} + \beta_2\,\ln BW_{it} + \beta_3\,\Delta\ln SALE_{it} \times \ln BW_{it} + \beta_4\,controls_{it} + B_5\,\Delta\ln SALE_{it} \times controls_{it} \\ & + \text{Industry dummies} + \text{Year dummies} + \varepsilon_{it}\end{aligned} \quad (1)$$

The dependent variable, $\Delta\ln COST_{it}$, indicates the log change in deflated costs for a firm from year $t-1$ to year t. We use three cost categories: sales, general, and administrative costs ($\Delta\ln SGA_{it}$), cost of goods sold ($\Delta\ln COGS_{it}$), and the number of employees ($\Delta\ln EMP_{it}$) (Banker et al., 2014). $\Delta\ln SALE_{it}$ represents the log change in deflated sales revenue for a firm from year $t-1$ to t. $\ln BW_{it}$ represents the logged value of the bullwhip measure. The slope β_3 measures the degree of cost rigidity, the proportional change in costs resulting from a 1 percent variation in sales revenue, associated with the bullwhip effect. If β_3 is positive, then a higher bullwhip effect decreases cost rigidity, leading to a more scalable short-run cost structure with lower fixed and higher variable costs. On the contrary, if β_3 is negative, then a greater bullwhip effect increases cost rigidity, indicating a more rigid short-run cost structure weighted toward fixed costs.

Banker et al. (2014) argue and find that demand uncertainty is positively associated with cost rigidity because firms would commit more capacity resources up front to mitigate congestion costs as uncertainty rises. Thus, we control demand uncertainty ($UNCERTAIN_{it}$), which is the standard deviation of the log changes in sales for all valid firm-year observations and its interaction with $\Delta lnSALE_t$. We also include GDP growth ($GDPRATE_{it}$) to account for macroeconomic trends and their interaction with $\Delta lnSALE_{it}$. In addition, we add economic determinants that can affect the cost structure used in M. A. Anderson et al. (2003). We control for successive sales decreases ($SUCDEC_{it}$), defined as a dummy variable set equal to 1 if sales have decreased from $t-1$ to t and $t-2$ to $t-1$, and 0 otherwise in its interaction with $\Delta lnSALE_t$. We expect $SUCDEC_{it}$ is negatively associated with cost rigidness because managers are more likely to consider a revenue decline in two consecutive years to be more permanent, causing them to be pessimistic and reduce fixed costs (Banker & Byzalov, 2014). We control for asset intensity ($lnASSINT_{it}$) and employee intensity ($lnEMPINT_{it}$) and their interactions with $\Delta lnSALE_{it}$. $lnASSINT_i$ is calculated as the logged value of the ratio of total assets to sales revenue in year *t*, and $lnEMPINT_{it}$ is calculated as the logged value of the ratio of the number of employees to sales revenue in year *t*. The degree of cost rigidness is likely to be higher for firms that rely more on their fixed assets. On the other hand, the usage of temporary workers and increases in the flexibility of labor decisions in recent years may cause employee intensity to be negatively correlated with cost rigidness (C. L. Chen et al., 2012). Industry (SIC 2-digit) dummies and year dummies are included to control different cost behaviors across industries and fiscal years.

3.2. The Measurement of the Bullwhip Effect

Following the measurement commonly used in previous studies, such as F. Chen et al. (2000), Cachon et al. (2007), Shan et al. (2014) and Osadchiy et al. (2016), we define Bullwhip Ratio as variability of production divided by variability of demand.[2] Based on the accounting identity, Production = Demand + End. Inventory—Beg. Inventory, Production in year t, quarter q is defined as cost of goods sold in year t, quarter q plus the change in inventory from year t, quarter $q-1$ to quarter q, while demand in year t, quarter q is defined as the cost of goods sold in year t, quarter q.[3]

Because the production and demand series pose a plausible unit root, the standard deviation of these series may depend on the length of the time horizon. Consistent with the studies cited above, we make logarithmic and first-difference transformations for both series to remove the time trend. Thus, BW_{it} is the standard deviation of quarterly production percentage changes (approximated with the natural log of production in year t, quarter q minus the natural log of production in year t, quarter $q-1$) in year t minus the standard deviation of quarterly demand percentage change (approximated with the natural log of demand in year t, quarter q minus the natural log of demand in year t, quarter $q-1$) in year t. That is,

$$BW = \sigma(\Delta \ln(Production_{it})) / \sigma(\Delta \ln(Demand_{it})),$$

where $\sigma(.)$ denotes the standard deviation of the logarithmic change in production ($\Delta \ln(Production_{it})$) or in demand (($\Delta \ln(Demand_{it})$) over the rolling window of the prior twelve quarters. By definition, a firm experiences the bullwhip effect when its purchase orders and production are more volatile than its customer orders (Bray & Mendelson, 2012). Hence, if the ratio is greater than 1, a bullwhip effect manifests in the firm.

3.3. Research Sample

We confine our sample to firms in the retailing, wholesaling, manufacturing, and resource-extracting sectors (SIC 5200–5999, 5000–5199, 2000–3999, and 1000–1400, respectively) between years 1979–2019 following the bullwhip literature (Bray & Mendelson, 2012). In addition, we deflate all financial variables to control for consumer price index (CPI). Following Banker et al. (2014), we consider the following three cost types: SG&A costs (Compustat data XSGA), COGS (Compustat data COGS), and number of employees (Compustat data EMP). The variable definitions are provided in Table 1. We first exclude firm-year observations if current or lagged sales or costs are missing, zero, or negative. Consistent with M. A. Anderson et al. (2003), we further exclude firm-year observations from the SG&A regressions in cases where SG&A costs exceed sales in the current or preceding year. To mitigate the influence of outliers, we trim 1st and 99th percentiles of the regression variables. The final sample comprises 77,626 firm-year observations for SG&A costs, 77,624 observations for COGS, and 77,222 observations for the number of employees. Descriptive statistics are presented in Table 2. The mean (median) deflated sales revenue is USD 2194 million (USD 240 million). On average, SG&A costs and COGS represent 26 percent and 64.6 percent of sales revenue, respectively. The mean (median) number of employees per firm is 9.747 (1.441). The mean (median) of the bullwhip measure is 1.346 (1.141). The mean (median) of demand uncertainty ($UNCERTAIN_{it}$) is 0.24 (0.19). The mean (median) of GDP growth rate is 2.766 (2.861). The mean of successive decrease is 0.142. The mean of asset intensity is 0.008, and the mean of employee intensity is 1.035. A correlation matrix among variables is presented in Table 3. The log change in sales ($\Delta lnSALE_{it}$) is positively associated with the three dependent variables, $\Delta lnSGA_{it}$, $\Delta lnCOGS_{it}$, and $\Delta lnEMP_{it}$. The bullwhip measure ($lnBW_{it}$) is positively associated with the log change in sales ($\Delta lnSALE_{it}$) and the log changes in three cost categories ($\Delta lnCOST_{it}$), but the magnitudes of these correlations are rather small.

Table 1. Variable definitions.

Variable	Definition
$\Delta lnSGA_{it}$	The log change in deflated sales, general, and administrative costs (Compustat data XSGA) of firm i in year t;
$\Delta lnCOGS_{it}$	The log change in deflated cost of goods sold (Compustat data COGS) of firm i in year t;
$\Delta lnEMP_{it}$	The log change in the number of employees (Compustat data EMP) of firm i in year t;
$\Delta lnSALE_{it}$	The log change in deflated sales (Compustat data SALE) of firm i in year t;
$lnBW_{it}$	The logged value of the bullwhip measure;
$UNCERTAIN_{it}$	Demand uncertainty measured by the standard deviation of log changes in sales for all valid observations of a firm;
$GDPRATE_{it}$	GDP growth rate from the previous year to the current year in year t;
$SUCDEC_{it}$	A dummy variable set equal to 1 if sales have decreased from $t-1$ to t and $t-2$ to $t-1$, and 0 otherwise;
$lnASSINT_{it}$	The logged value of the ratio of total assets to sales revenue in year t;
$lnEMPINT_{it}$	The logged value of the ratio of the number of employees to sales revenue in year t;
$LEASEBUY_{it}$	(operating lease expense + rent expense)/(operating lease expense (Compustat data MRC1) + rent expense (Compustat data XRENT) + depreciation (Compustat data DP));
$\Delta lnOLEASE_{it}$	The log change in deflated operating lease use measured as one-year-ahead operating lease payments (Compustat data MRC1) of firm i in year t;
$\Delta lnRENT_{it}$	The log change in deflated rental expense (Compustat data XRENT) of firm i in year t.

Table 2. Descriptive Statistics.

	N	Mean	Std. Dev.	p25	Median	p75
$SALE_{it}$	77,626	2193.733	10,551.334	49.162	239.605	1087.708
SGA_{it}	77,626	400.101	1937.47	11.033	46.502	198.113
$SGA_{it}/SALE_{it}$	77,626	0.26	0.167	0.135	0.226	0.346
$COGS_{it}$	77,626	1494.95	7826.358	29.327	149.326	701.104
$COGS_{it}/SALE_{it}$	77,626	0.646	0.194	0.538	0.669	0.769
EMP_{it}	77,626	9.747	42.894	0.3	1.441	6
BW_{it}	77,626	1.346	0.739	0.944	1.141	1.537
$UNCERTAIN_{it}$	77,626	0.235	0.173	0.126	0.192	0.29
$GDPRATE_{it}$	77,626	2.766	1.768	1.876	2.861	4.029
$SUCDEC_{it}$	77,626	0.142	0.349	0	0	0
$ASSINT_{it}$	77,626	0.008	0.007	0.003	0.006	0.01
$EMPINT_{it}$	77,626	1.035	0.928	0.576	0.8	1.166
$LEASEBUY_{it}$	77,626	0.405	0.259	0.207	0.398	0.603
$OLEASE_{it}$	65,178	27.821	103.849	0.757	3.297	16.007
$RENT_{it}$	67,123	33.490	129.047	0.841	3.800	19.700

Variables are defined in Table 1.

Table 3. Correlations.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) $\Delta lnSGA_{it}$	1.000										
(2) $\Delta lnCOGS_{it}$	0.572 ***	1.000									
(3) $\Delta lnEMP_{it}$	0.490 ***	0.501 ***	1.000								
(4) $\Delta lnSALE_{it}$	0.636 ***	0.864 ***	0.549 ***	1.000							
(5) $lnBW_{it}$	0.017 ***	0.015 ***	0.019 ***	0.017 ***	1.000						
(6) $UNCERTAIN_{it}$	0.023 ***	0.037 ***	−0.006 *	0.023 ***	0.014 ***	1.000					
(7) $GDPRATE_{it}$	0.112 ***	0.146 ***	0.102 ***	0.161 ***	−0.040 ***	0.013 ***	1.000				
(8) $SUCDEC_{it}$	−0.333 ***	−0.379 ***	−0.268 ***	−0.415 ***	0.004	0.071 ***	−0.084 ***	1.000			
(9) $lnASSINT_{it}$	0.041 ***	0.014 ***	0.060 ***	−0.007 *	0.057 ***	0.200 ***	−0.044 ***	0.026 ***	1.000		
(10) $lnEMPINT_{it}$	−0.044 ***	−0.071 ***	0.017 ***	−0.084 ***	−0.065 ***	−0.101 ***	0.128 ***	0.037 ***	−0.137 ***	1.000	
(11) $LEASEBUY_{it}$	0.009 ***	0.002	0.019 ***	0.006	−0.003	−0.040 ***	−0.013 ***	0.015 ***	−0.422 ***	0.121 ***	1.000

***, * refer to significance at the 1%, and 10% levels, respectively.

4. Empirical Results

Table 4 presents the results of the basic cost rigidness model with the log changes in SG&A costs, COGS, and the number of employees as dependent variables. The coefficient estimate of $\Delta lnSALE_{it}$ measures the average short-run response of costs to a 1 percent change in sales, serving as an indicator of cost rigidity. On average, a 1 percent increase in sales is associated with a 0.54 percent rise in SG&A costs, a 0.89 percent increase in COGS, and a 0.50 percent increase in the number of employees, which are comparable with the findings of Banker et al. (2014). Next, our variable of interest, the interaction variable between $lnSALE_{it}$ and lnBW, captures the relationship between the bullwhip effect and cost rigidity. For each of three cost categories, the coefficient estimate of the test variable, $\Delta lnSALE_{it} \times lnBW_{it}$, is positive and significant at the 1 percent significance level. Thus, a higher intensity of the bullwhip effect is associated with a less rigid short-run cost structure, as Hypothesis 1 predicts.

Table 5 presents the results of the cost rigidness model with control variables that determine the cost structure. We include demand uncertainty, GDP growth rate, successive sales decrease, asset intensity, and employee intensity as control variables. Similarly to Table 4, for each of the three cost categories, the coefficient estimate of the test variable, the interaction term between $\Delta lnSALE_{it}$ and lnBW, is positive and significant at the 1 percent significance level. We confirm that a higher intensity of the bullwhip effect is associated with a less rigid short-run cost structure. Consistent with Banker et al. (2014), the interaction variable, $\Delta lnSALE_{it} \times UNCERTAIN_{it}$, is negative and significant at the 1 percent significance level for each of the three cost types. The results indicate that firms would incur higher fixed costs under elevated uncertainty as a means to reduce congestion costs.

In addition, we find that the interaction variable, $\Delta lnSALE_{it} \times lnASSINT_{it}$, is significantly negative and the interaction variable, $\Delta lnSALE_{it} \times lnEMPINT_{it}$, is significantly positive. Higher asset intensity and lower employee intensity are associated with a more rigid short-run cost structure. The relationship between the bullwhip effect and cost rigidity is also economically significant. For example, at the lower quartile of the bullwhip effect, the percentage change in costs for a 1 percent change in sales is equal to 0.54 percent for SG&A costs, 0.92 percent for COGS, and 0.50 percent for the number of employees. At the upper quartile of the bullwhip effect, the response of costs to a 1 percent change in sales is substantially stronger: 0.64 percent for SG&A costs, an increase of 19 percent, 0.93 percent for COGS, an increase of 1 percent, and 0.59 percent for the number of employees, an increase of 18 percent.

Table 4. Basic cost rigidness model.

Variables	Pred. Sign	(1) $\Delta lnSGA_{it}$	(2) $\Delta lnCOGS_{it}$	(3) $\Delta lnEMP_{it}$
$\Delta lnSALE_{it}$		0.541 ***	0.894 ***	0.496 ***
		(91.588)	(173.035)	(83.858)
lnBW		−0.000	−0.000	0.001
		(−0.112)	(−0.210)	(0.996)
$\Delta lnSALE_{it} \times lnBW$	**H1: (+)**	**0.107 *** **	**0.049 *** **	**0.099 *** **
		(10.147)	**(6.374)**	**(9.063)**
Constant		0.004	0.035 ***	0.018
		(0.301)	(3.052)	(1.514)
Year fixed effect		Yes	Yes	Yes
Industry fixed effect		Yes	Yes	Yes
Observations		79,670	79,667	77,352
Adjusted R-squared		0.405	0.739	0.308
F-statistic		198.86 ***	1011.83 ***	163.94 ***

All regressions are estimated using robust standard errors clustered by firm, and *p*-values are calculated as one-tailed where signs are predicted, and two-tailed otherwise. *** refers to significance at the 1% level. Variables are defined in Table 1.

Table 5. Cost rigidness model with control variables.

Variables	Pred. Sign	(1) $\Delta lnSGA_{it}$	(2) $\Delta lnCOGS_{it}$	(3) $\Delta lnEMP_{it}$
$\Delta lnSALE_{it}$		0.733 ***	1.073 ***	0.790 ***
		(23.828)	(37.002)	(24.691)
lnBW		−0.001	−0.000	0.001
		(−1.138)	(−0.090)	(0.653)
$\Delta lnSALE_{it} \times lnBW$	**H1: (+)**	**0.091 *** **	**0.044 *** **	**0.086 *** **
		(9.000)	**(5.874)**	**(8.284)**
$UNCERTAIN_{it}$		0.023 ***	0.019 ***	−0.011 *
		(4.500)	(5.094)	(−1.885)
$GDPRATE_{it}$		0.004	0.006 ***	0.001
		(1.301)	(3.319)	(0.179)
$SUCDEC_{it}$		−0.042 ***	−0.012 ***	−0.026 ***
		(−16.584)	(−4.815)	(−9.248)
$lnASSINT_{it}$		0.030 ***	0.011 ***	0.036 ***
		(20.969)	(8.690)	(21.042)

Table 5. *Cont.*

Variazbles	Pred. Sign	(1) $\Delta lnSGA_{it}$	(2) $\Delta lnCOGS_{it}$	(3) $\Delta lnEMP_{it}$
$lnEMPINT_{it}$		−0.003 **	0.001	0.031 ***
		(−2.382)	(1.099)	(20.527)
$\Delta lnSALE_{it} \times UNCERTAIN_{it}$		−0.222 ***	−0.051 ***	−0.253 ***
		(−6.717)	(−2.875)	(−8.178)
$\Delta lnSALE_{it} \times GDPRATE_{it}$		0.014 ***	−0.005 ***	0.011 ***
		(6.047)	(−2.623)	(4.402)
$\Delta lnSALE_{it} \times SUCDEC_{it}$		−0.011	−0.006	−0.020
		(−0.784)	(−0.390)	(−1.208)
$\Delta lnSALE_{it} \times lnASSINT_{it}$		−0.079 ***	−0.120 ***	−0.060 ***
		(−10.671)	(−15.645)	(−8.376)
$\Delta lnSALE_{it} \times lnEMPINT_{it}$		0.031 ***	0.027 ***	0.044 ***
		(6.011)	(4.908)	(8.160)
Constant		−0.021	0.036 ***	0.153 ***
		(−1.640)	(3.103)	(11.540)
Year fixed effect		Yes	Yes	Yes
Industry fixed effect		Yes	Yes	Yes
Observations		77,626	77,624	77,222
Adjusted R-squared		0.432	0.757	0.337
F-statistic		284.88 ***	1575.75 ***	218.8 ***

All regressions are estimated using robust standard errors clustered by firm, and *p*-values are calculated as one-tailed where signs are predicted, and two-tailed otherwise. ***, **, * refer to significance at the 1%, 5%, and 10% levels, respectively. Variables are defined in Table 1.

Overall, the regression results for SG&A and COGS costs support our research hypothesis that firms with a higher intensity of the bullwhip effect exhibit a less rigid cost structure. Importantly, the regression results for employees imply that firms would hire more contract employees to lower labor adjustment costs in the presence of the bullwhip effect. This is consistent with the argument that firms would increase the share of contract labor relative to full-time employees in response to increases in demand uncertainty and financial risk (Holzhacker et al., 2015a).

4.1. Mediation Analyses

We examine the mediator role of lease vs. buy decision in our main regressions as shown in Equations (2) and (3) below to test Hypothesis 2. The Seemingly Unrelated Regression (SUR) allows us to test (1) the extent of association between bullwhip effect and lease vs. buy choice and (2) the extent of relationship between lease vs. buy choice and cost rigidity (Holzhacker et al., 2015a). According to Hypothesis 2, we expect that both the coefficient (α_1) on $lnBW_{it}$ in Equation (3) and the coefficient (β_5) on the interaction term, $\Delta lnSALE_{it} \times LEASEBUY_{it}$, in Equation (2) to be significantly positive.

$$\Delta lnCOST_{it} = \beta_0 + \beta_1 \Delta lnSALE_{it} + \beta_2 lnBW_{it} + \beta_3 \Delta lnSALE_{it} \times lnBW_{it} + \beta_4 LEASEBUY_{it} + \beta_5 \Delta lnSALE_{it} \times LEASEBUY_{it} + \beta_6 controls_{it} + \beta_7 x\Delta lnSALE_{it} \times controls_{it} + Industry\ dummies + Year\ dummies + \varepsilon_{it} \quad (2)$$

$$LEASEBUY_{it} = \alpha_0 + \alpha_1 lnBW_{it} + \alpha_2 controls_{it} + Industry\ dummies + Year\ dummies + \mu_{it} \quad (3)$$

Columns 1 and 2 in Table 6 contain the SUR regression results when Equations (2) and (3) are estimated as a system (System I) using $\Delta lnSGA_{it}$ as the dependent variable. Columns 3 and 4 contain the regression results (System II) when cost is measured by cost of goods sold ($COGS_{it}$). As shown in columns (1) and (3), the significantly positive effect of $lnBW_{it}$ on $LEASEBUY_{it}$ ($p < 0.01$) suggests that firms significantly increase their share of leased or rented equipment in response to a higher bullwhip effect. The significantly positive coefficients on $\Delta lnSALE_{it} \times LEASEBUY_{it}$ in columns (2) and (4) reveal that firms

with a higher proportion of lease or rent usage of equipment relative to buying on average have a more flexible cost structure. Further, for both systems, the products of coefficients, $\alpha_1 \times \beta_5$, are significantly positive at the 1 percent level (Z = 6.64 for $lnBW_{it}$ in Column 1 × $\Delta lnSALE_{it}$ × $LEASEBUY_{it}$ in Column 2, and Z = 3.84 for $lnBW_{it}$ in Column 3 × $\Delta lnSALE_{it}$ × $LEASEBUY_{it}$ in Column 4). These results show that, consistent with Hypothesis 2, the positive relationship between the bullwhip effect and cost rigidity is mediated by lease vs. buy decision ($LEASEBUY_{it}$). This finding implies that in response to the bullwhip effect, managers increase the extent of leasing or renting of equipment relative to equipment purchases to reduce cost rigidity.

Table 6. Mediation Analyses.

	Pred.	**System I**		**System II**	
Variables	**Sign**	**(1) $LEASEBUY_{it}$**	**(2) $\Delta lnSGA_{it}$**	**(3) $LEASEBUY_{it}$**	**(4) $\Delta lnCOGS_{it}$**
lnBW	**H2: (+)**	**0.014 *** **		**0.014 *** **	
		(7.93)		**(7.92)**	
$UNCERTAIN_{it}$		0.120 ***		0.120 ***	
		(26.53)		(26.55)	
$GDPRATE_{it}$		−0.030 ***		−0.030 ***	
		(−6.57)		(−6.56)	
$SUCDEC_{it}$		0.015 ***		0.015 ***	
		(7.03)		(7.02)	
$lnASSINT_{it}$		−0.128 ***		−0.128 ***	
		(−80.74)		(−80.67)	
$lnEMPINT_{it}$		0.020 ***		0.020 ***	
		(15.63)		(15.64)	
$\Delta lnSALE_{it}$			0.666 ***		1.054 ***
			(38.78)		(79.54)
lnBW			−0.001		−0.000
			(−1.08)		(−0.12)
$\Delta lnSALE_{it}$ × lnBW	H1: (+)		**0.088 *** **		**0.043 *** **
			(14.92)		**(9.47)**
$LEASEBUY_{it}$			0.074 ***		0.005 **
			(2.88)		(2.28)
$\Delta lnSALE_{it}$ × $LEASEBUY_{it}$	**H2: (+)**		**0.125 *** **		**0.035 *** **
			(12.17)		**(4.40)**
$UNCERTAIN_{it}$			0.022 ***		0.018 ***
			(6.74)		(7.24)
$GDPRATE_{it}$			0.003		0.006 **
			(1.03)		(2.22)
$SUCDEC_{it}$			−0.042 ***		−0.012 ***
			(−18.39)		(−6.68)
$lnASSINT_{it}$			0.030 ***		0.011 ***
			(25.50)		(12.49)
$lnEMPINT_{it}$			−0.003 ***		0.001
			(−2.97)		(1.20)
$\Delta lnSALE_{it}$ × $UNCERTAIN_{it}$			−0.228 ***		−0.052 ***
			(−20.72)		(−6.17)
$\Delta lnSALE_{it}$ × $GDPRATE_{it}$			0.014 ***		−0.005 ***
			(9.93)		(−4.64)
$\Delta lnSALE_{it}$ × $SUCDEC_{it}$			−0.012		−0.006
			(−1.27)		(−0.84)
$\Delta lnSALE_{it}$ × $lnASSINT_{it}$			−0.059 ***		−0.114 ***
			(−15.28)		(−38.50)
$\Delta lnSALE_{it}$ × $lnEMPINT_{it}$			0.028 ***		0.026 ***
			(9.96)		(12.13)
Constant		0.199 ***	−0.022 **	0.199 ***	0.035 ***
		(14.92)	(−2.28)	(14.92)	(4.80)
Year fixed effect		Yes	Yes	Yes	Yes
Industry fixed effect		Yes	Yes	Yes	Yes
Observations		77,626	77,626	77,624	77,624
Adjusted R-squared		0.456	0.434	0.370	0.757
Chi-square Statistic		45,646.46 ***	59,604.61 ***	45,640.84 ***	242,394.77 ***

$LEASEBUY_{it}$ is defined as (operating lease expense + rent expense)/(operating lease expense (Compustat data MRC1) + rent expense (Compustat data XRENT) + depreciation (Compustat data DP)). *p*-values are calculated as one-tailed where signs are predicted, and two-tailed otherwise. ***, ** refer to significance at the 1% and 5% levels, respectively. Other variables are defined in Table 1.

4.2. Robustness Checks

In Table 7, we estimate the firm fixed-effect model to address omitted variable bias. The results show that the interaction variable, $\Delta lnSALE_{it} \times lnBW$, is positive and significant at the 1 percent significance level and reinforce our main hypothesis that a higher intensity of the bullwhip effect is associated with a less rigid short-run cost structure. In Table 8, we use the raw bullwhip measure in place of the logged value in the regressions. Panel A shows results using the ratio of variability in production divided by variability in demand as a bullwhip measure, and Panel B presents results using the difference between variability in production and variability in demand as a bullwhip measure. For each of three cost categories, the results corroborate the main finding that the bullwhip effect is negatively associated with a rigid short-run cost structure. We further estimate the main regressions presented in Table 5 using the Fama–MacBeth procedure (Fama & MacBeth, 1973), which involves aggregating coefficients from annual cross-sectional regressions. This method offers a robust complementary test, as it accounts for potential year-to-year variation in the underlying regression parameters, thereby addressing concerns related to long-term structural shifts in cost behavior. The Fama–MacBeth estimates for the test variable ($\Delta lnSALEit \times lnBW$) are consistent in magnitude with those obtained from our baseline regressions and significantly positive ($p < 0.01$) in Table 9. Thus, our main results are robust to potential long-term structural shifts in cost behavior.

Table 7. Firm fixed effect model.

Variables	Pred. Sign	(1) $\Delta lnSGA_{it}$	(2) $\Delta lnCOGS_{it}$	(3) $\Delta lnEMP_{it}$
$\Delta lnSALE_{it}$		0.659 ***	1.074 ***	0.732 ***
		(20.423)	(31.772)	(22.125)
lnBW		−0.004 ***	0.001	−0.004 *
		(−2.783)	(0.735)	(−1.792)
$\Delta lnSALE_{it} \times lnBW$	**H1: (+)**	**0.093 *** **	**0.046 *** **	**0.081 *** **
		(8.422)	**(5.601)**	**(7.571)**
$GDPRATE_{it}$		0.012 ***	0.005 **	−0.045 ***
		(3.903)	(2.543)	(−10.499)
$SUCDEC_{it}$		−0.039 ***	−0.014 ***	−0.024 ***
		(−14.740)	(−5.447)	(−8.056)
$lnASSINT_{it}$		0.056 ***	0.016 ***	0.072 ***
		(18.701)	(6.534)	(18.735)
$lnEMPINT_{it}$		0.010 ***	0.005 **	0.171 ***
		(3.510)	(2.015)	(31.925)
$\Delta lnSALE_{it} \times GDPRATE_{it}$		0.012 ***	−0.005 **	0.006 **
		(5.223)	(−2.552)	(2.255)
$\Delta lnSALE_{it} \times SUCDEC_{it}$		0.014	−0.003	0.021
		(0.911)	(−0.188)	(1.234)
$\Delta lnSALE_{it} \times lnASSINT_{it}$		−0.093 ***	−0.127 ***	−0.063 ***
		(−11.654)	(−14.994)	(−8.279)
$\Delta lnSALE_{it} \times lnEMPINT_{it}$		0.037 ***	0.031 ***	0.049 ***
		(6.583)	(5.029)	(8.504)
Constant		0.113 ***	0.043 ***	0.793 ***
		(9.014)	(4.265)	(34.181)
Year fixed effect		Yes	Yes	Yes
Industry fixed effect		No	No	No
Firm fixed effect		Yes	Yes	Yes
Observations		77,759	77,757	77,352
Number of firms		7616	7616	7590
Adjusted R-squared		0.389	0.744	0.345
F-statistic		320.24 ***	1889.68 ***	285.32 ***

All regressions are estimated using firm-fixed effect model, and *p*-values are calculated as one-tailed where signs are predicted, and two-tailed otherwise. ***, **, * refer to significance at the 1%, 5%, and 10% levels, respectively. Variables are defined in Table 1.

Table 8. Raw bullwhip measure.

Panel A Ratio				
Variables	**Pred. Sign**	**(1)** $\Delta lnSGA_{it}$	**(2)** $\Delta lnCOGS_{it}$	**(3)** $\Delta lnEMP_{it}$
$\Delta lnSALE_{it}$		0.694 ***	1.056 ***	0.749 ***
		(21.714)	(36.245)	(22.619)
BW		−0.002 **	−0.000	−0.000
		(−2.421)	(−0.501)	(−0.558)
$\Delta lnSALE_{it} \times BW$	**H1: (+)**	**0.042 *** **	**0.019 *** **	**0.043 *** **
		(7.312)	**(4.848)**	**(7.406)**
$UNCERTAIN_{it}$		0.023 ***	0.019 ***	−0.011 *
		(4.488)	(5.115)	(−1.877)
$GDPRATE_{it}$		0.004	0.006 ***	0.001
		(1.283)	(3.311)	(0.164)
$SUCDEC_{it}$		−0.041 ***	−0.012 ***	−0.026 ***
		(−16.493)	(−4.771)	(−9.188)
$lnASSINT_{it}$		0.030 ***	0.011 ***	0.037 ***
		(21.124)	(8.775)	(21.136)
$lnEMPINT_{it}$		−0.002 **	0.001	0.031 ***
		(−2.350)	(1.123)	(20.544)
$\Delta lnSALE_{it} \times UNCERTAIN_{it}$		−0.224 ***	−0.052 ***	−0.255 ***
		(−6.782)	(−2.968)	(−8.245)
$\Delta lnSALE_{it} \times GDPRATE_{it}$		0.014 ***	−0.005 ***	0.011 ***
		(5.957)	(−2.664)	(4.348)
$\Delta lnSALE_{it} \times SUCDEC_{it}$		−0.012	−0.006	−0.021
		(−0.801)	(−0.390)	(−1.237)
$\Delta lnSALE_{it} \times lnASSINT_{it}$		−0.079 ***	−0.120 ***	−0.060 ***
		(−10.668)	(−15.629)	(−8.369)
$\Delta lnSALE_{it} \times lnEMPINT_{it}$		0.031 ***	0.027 ***	0.044 ***
		(5.904)	(4.870)	(8.062)
Constant		−0.019	0.036 ***	0.153 ***
		(−1.547)	(3.098)	(11.490)
Year fixed effect		Yes	Yes	Yes
Industry fixed effect		Yes	Yes	Yes
Observations		77,626	77,624	77,222
Adjusted R-squared		0.432	0.757	0.336
F-statistic		282.81 ***	1562.37 ***	218.88 ***
Panel B Difference				
Variables	**Pred. Sign**	**(1)** $\Delta lnSGA_{it}$	**(2)** $\Delta lnCOGS_{it}$	**(3)** $\Delta lnEMP_{it}$
$\Delta lnSALE_{it}$		0.748 ***	1.075 ***	0.804 ***
		(24.192)	(36.803)	(25.079)
BW		−0.015 ***	0.001	−0.018 ***
		(−3.351)	(0.189)	(−3.466)
$\Delta lnSALE_{it} \times BW$	**H1: (+)**	**0.087 *** **	**0.087 *** **	**0.084 *** **
		(3.550)	**(4.614)**	**(3.298)**
$UNCERTAIN_{it}$		0.024 ***	0.019 ***	−0.009 *
		(4.651)	(5.031)	(−1.650)
$GDPRATE_{it}$		0.004	0.006 ***	0.001
		(1.296)	(3.306)	(0.187)

Table 8. *Cont.*

Panel B Difference				
Variables	**Pred. Sign**	**(1)** $\Delta lnSGA_{it}$	**(2)** $\Delta lnCOGS_{it}$	**(3)** $\Delta lnEMP_{it}$
$SUCDEC_{it}$		−0.042 ***	−0.012 ***	−0.027 ***
		(−16.583)	(−4.936)	(−9.272)
$lnASSINT_{it}$		0.030 ***	0.011 ***	0.037 ***
		(21.343)	(8.760)	(21.471)
$lnEMPINT_{it}$		−0.003 **	0.001	0.031 ***
		(−2.509)	(1.045)	(20.350)
$\Delta lnSALE_{it} \times UNCERTAIN_{it}$		−0.233 ***	−0.057 ***	−0.264 ***
		(−6.919)	(−3.243)	(−8.377)
$\Delta lnSALE_{it} \times GDPRATE_{it}$		0.013 ***	−0.005 ***	0.011 ***
		(5.839)	(−2.717)	(4.224)
$\Delta lnSALE_{it} \times SUCDEC_{it}$		−0.013	−0.008	−0.023
		(−0.908)	(−0.486)	(−1.355)
$\Delta lnSALE_{it} \times lnASSINT_{it}$		−0.079 ***	−0.120 ***	−0.060 ***
		(−10.630)	(−15.621)	(−8.307)
$\Delta lnSALE_{it} \times lnEMPINT_{it}$		0.031 ***	0.026 ***	0.043 ***
		(5.842)	(4.787)	(7.989)
Constant		−0.023 *	0.035 ***	0.150 ***
		(−1.809)	(3.051)	(11.328)
Year fixed effect		Yes	Yes	Yes
Industry fixed effect		Yes	Yes	Yes
Observations		77,626	77,624	77,222
Adjusted R-squared		0.431	0.757	0.336
F-statistic		278.62 ***	1544.96 ***	216.75 ***

All regressions are estimated using robust standard errors clustered by firm, and *p*-values are calculated as one-tailed where signs are predicted, and two-tailed otherwise. ***, **, * refer to significance at the 1%, 5%, and 10% levels, respectively. Variables are defined in Table 1.

Table 9. Fama–Macbeth Regressions.

Variables	**Pred. Sign**	**(1)** $\Delta lnSGA_{it}$	**(2)** $\Delta lnCOGS_{it}$	**(3)** $\Delta lnEMP_{it}$
$\Delta lnSALE_{it}$		0.062 *	0.084 **	0.068 **
		(1.981)	(2.028)	(2.040)
lnBW		0.000	−0.001	0.002
		(0.154)	(−1.071)	(1.411)
$\Delta lnSALE_{it} \times lnBW$	**H1: (+)**	**0.097 *** **	**0.037 *** **	**0.093 *** **
		(9.906)	**(3.961)**	**(6.387)**
$UNCERTAIN_{it}$		0.014 **	0.019 ***	−0.017 *
		(2.320)	(3.738)	(−1.926)
$GDPRATE_{it}$		0.010 ***	0.001	0.034 ***
		(4.019)	(0.243)	(7.122)
$SUCDEC_{it}$		−0.039 ***	−0.007 **	−0.027 ***
		(−18.173)	(−2.424)	(−7.256)
$lnASSINT_{it}$		0.016 ***	0.010 ***	0.024 ***
		(7.509)	(4.017)	(11.992)
$lnEMPINT_{it}$		0.002	0.001	0.024 ***
		(1.352)	(0.575)	(10.078)
$\Delta lnSALE_{it} \times UNCERTAIN_{it}$		−0.255 ***	−0.038 **	−0.316 ***
		(−8.710)	(−2.076)	(−10.576)

Table 9. *Cont.*

Variables	Pred. Sign	(1) $\Delta lnSGA_{it}$	(2) $\Delta lnCOGS_{it}$	(3) $\Delta lnEMP_{it}$
$\Delta lnSALE_{it} \times GDPRATE_{it}$		0.169 ***	0.288 ***	0.192 ***
		(5.122)	(6.959)	(5.453)
$\Delta lnSALE_{it} \times SUCDEC_{it}$		−0.024	0.017	−0.021
		(−1.467)	(0.875)	(−0.919)
$\Delta lnSALE_{it} \times lnASSINT_{it}$		−0.072 ***	−0.097 ***	−0.048 ***
		(−8.373)	(−8.430)	(−4.774)
$\Delta lnSALE_{it} \times lnEMPINT_{it}$		0.024 ***	0.014	0.033 ***
		(4.212)	(1.425)	(4.794)
Constant		0.002	−0.001	0.010 *
		(0.956)	(−0.713)	(1.834)
Observations		77,626	77,624	77,222
Adjusted R-squared		0.422	0.755	0.324
Number of years		41	41	41
F-statistic		111.23 ***	33.04 ***	101.68 ***

All regressions are estimated using Fama–Macbeth procedures, and *p*-values are calculated as one-tailed where signs are predicted, and two-tailed otherwise. ***, **, * refer to significance at the 1%, 5%, and 10% levels, respectively. Variables are defined in Table 1.

In Table 10, we estimate regressions using operating lease expense and rental expense in place of sales, general, and administrative expenses as dependent variables. Because firms with a higher bullwhip effect tend to lease or rent assets to expand capacity, we expect that their operating lease and rental expenses are more responsive to changes in sales. As shown in Table 10, the coefficients of the test variable (ΔlnSALEit × lnBW) are positive and significant ($p < 0.01$) when the dependent variable is the log change in operating lease use and rental expenses, corroborating our main results for Hypothesis 2.

Table 10. Operating Lease and Rental Expenses.

Variables	Pred. Sign	(1) $\Delta lnOLEASE_{it}$	(2) $\Delta lnRENT_{it}$
$\Delta lnSALE_{it}$		0.808 ***	0.956 ***
		(10.243)	(12.802)
lnBW		−0.001	−0.004
		(−0.362)	(−1.486)
$\Delta lnSALE_{it} \times lnBW$	**H2: (+)**	**0.084 *** **	**0.094 *** **
		(3.235)	**(4.271)**
$UNCERTAIN_{it}$		0.050 ***	0.115 ***
		(3.363)	(7.038)
$GDPRATE_{it}$		0.029 ***	−0.028 ***
		(3.417)	(−2.770)
$SUCDEC_{it}$		−0.047 ***	−0.068 ***
		(−6.368)	(−10.650)
$lnASSINT_{it}$		0.047 ***	0.032 ***
		(12.746)	(9.086)
$lnEMPINT_{it}$		0.007 **	−0.002
		(2.462)	(−0.894)
$\Delta lnSALE_{it} \times UNCERTAIN_{it}$		−0.130 *	−0.130
		(−1.675)	(−1.608)

Table 10. *Cont.*

Variables	Pred. Sign	(1) $\Delta lnOLEASE_{it}$	(2) $\Delta lnRENT_{it}$
$\Delta lnSALE_{it} \times GDPRATE_{it}$		0.027 ***	0.022 ***
		(4.424)	(3.973)
$\Delta lnSALE_{it} \times SUCDEC_{it}$		0.006	−0.044
		(0.148)	(−1.234)
$\Delta lnSALE_{it} \times lnASSINT_{it}$		−0.039 **	−0.027
		(−2.180)	(−1.643)
$\Delta lnSALE_{it} \times lnEMPINT_{it}$		0.067 ***	0.092 ***
		(5.017)	(7.405)
Constant		0.018	0.012
		(0.450)	(0.302)
Year fixed effect		Yes	Yes
Industry fixed effect		Yes	Yes
Observations		65,178	67,123
Adjusted R-squared		0.080	0.109
F-statistic		45.11 ***	59.31 ***

$\Delta lnOLEASE_{it}$ is log-change in deflated operating lease use measured as one-year-ahead operating lease payments (Compustat data MRC1) of firm i in year t. $\Delta lnRENT_{it}$ is log-change in deflated rental expense (Compustat data XRENT) of firm i in year t. All regressions are estimated using robust standard errors clustered by firm, and *p*-values are calculated as one-tailed where signs are predicted, and two-tailed otherwise. ***, **, * refer to significance at the 1%, 5%, and 10% levels, respectively. Other variables are defined in Table 1.

We also estimate the model with the inclusion of control variables (a dummy variable indicating a sales decrease from the previous year to the current year and its interaction with ΔlnSALEit) to account for cost stickiness (M. A. Anderson et al., 2003). For each of three cost types, the coefficients of the test variable (ΔlnSALEit × lnBW) are positive and significant ($p < 0.01$) (untabulated). Thus, our findings remain robust even after controlling for cost stickiness. The magnitude of cost response can be influenced by capacity utilization. Thus, we also account for two alternative proxies for capacity utilization, changes in firm size, measured by the log change in total assets, and the log change in net PP&E (Banker et al., 2014), and rerun regressions and obtain results (untabulated) similar to those in Table 5. There was a significant improvement in information technology in 1995 (Bray & Mendelson, 2012). To check whether there was a change in the bullwhip effect on cost rigidness due to information technology change, we divide the full sample into two subsamples before and after 1995. Untabulated results show that coefficients of $\Delta lnSALE_{it} \times lnBW$ are significantly positive ($p < 0.01$) across three regressions in both subsamples. It seems that there was no noticeable change in our results due to information technology change.

5. Conclusions

We examined the relationship between the firm-level bullwhip effect and cost rigidity using a large sample of U.S. public firms for the period 1980–2019. We hypothesized that firms having a higher intensity of the bullwhip effect are likely to adopt a more flexible short-term cost structure to mitigate the operating risk caused by the distorted information in supply chains. Using the log change in costs as a dependent variable, we found that, after controlling for economic determinants of the cost structure, the interaction term between the bullwhip effect and the log change in sales is significantly positively associated with the log change in costs at the 1 percent significance level. Furthermore, the regression results for employees, operating leases, and rental expenses indicate that, in the presence of the bullwhip effect, firms tend to hire more contract employees and increase asset leasing to lower adjustment costs and manage the risk associated with cost structure. These

results suggest that the firm-level bullwhip effect would impose higher operating risk on companies, leading to a less rigid cost structure.

Our research is interdisciplinary in that it expands our knowledge in both areas of cost management and supply chain management. Overall, our results are consistent with the conventional wisdom that companies confronting higher operating risk will choose a cost structure with high variable and low fixed costs. Our research sheds light on how the bullwhip effect affects managers' deliberate resource commitment decisions and provides policy implications for the recent global supply chain disruptions during the COVID pandemic. For instance, governments could launch economic stimulus and relief programs for firms to reduce the downside risk and avoid the pitfall of the bullwhip effect. Future research can explore how the bullwhip effect affects other accounting outcomes such as earnings quality and audit quality.

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Notes

1 https://www.wsj.com/articles/commentary-cautionbullwhip-effect-ahead-11623664801 (accessed at 23 October 2022).

2 Here, variability refers to the standard deviation, which is a measure of dispersion in statistics.

3 It is common in the supply chain management literature to assume production equal to orders and demand equal to cost of goods sold (e.g., Bray & Mendelson, 2012; Shan et al., 2014). However, the total inventory account in Compustat includes raw materials, work-in-process, and finished goods inventories. This accounting identity, which computes production based on the cost of goods sold and inventory changes, provides only an approximation of actual production during the accounting period. Furthermore, accounting noise in quarterly data, such as inaccurate recording of sales transactions at the end of the quarter, changes in cost flow assumptions (e.g., FIFO/LIFO), and seasonal adjustments, may distort estimates of cost of goods sold and inventory changes.

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