Management Science

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

The Bullwhip Effect in Servitized Manufacturers

Yimeng Niu, Jing Wu, Shenyang Jiang, Zhibin Jiang

informs
https://pubsonline.informs.org/journal/mnsc

MANAGEMENT SCIENCE
Articles in Advance, pp. 1–20
ISSN 0025-1909 (print), ISSN 1526-5501 (online)

The Bullwhip Effect in Servitized Manufacturers

Yimeng Niu,[a] Jing Wu,[b,]* Shenyang Jiang,[c,d] Zhibin Jiang[a,]*

[a] Antai College of Economics and Management, Shanghai Jiao Tong University, Shanghai 200240, China; [b] CUHK Business School, The Chinese University of Hong Kong, Hong Kong; [c] Advanced Institute of Business, Tongji University, Shanghai 200070, China; [d] Department of Logistics and Maritime Studies, The Hong Kong Polytechnic University, Hong Kong, China

*Corresponding authors

Contact: yimeng_niu@sjtu.edu.cn, https://orcid.org/0000-0002-0347-2631 (YN); jingwu@cuhk.edu.hk, https://orcid.org/0000-0002-0153-7710 (JW); shenyangjiang@tongji.edu.cn, https://orcid.org/0000-0002-0582-2762 (SJ); zbjiang@sjtu.edu.cn, https://orcid.org/0000-0002-9241-0212 (ZJ)

Received: December 21, 2021
Revised: August 19, 2023
Accepted: September 3, 2023
Published Online in Articles in Advance: April 25, 2024

https://doi.org/10.1287/mnsc.2023.01026

Abstract. The shift to a service-oriented economy has driven traditional product-oriented manufacturing firms to integrate various services into their businesses. This study aims to provide empirical evidence on how manufacturers' service offerings impact demand variability and intrafirm bullwhip effects. Through "bag-of-words" text mining on 10-K filings of U.S.-listed manufacturing firms, we propose a novel measurement to identify annual services offered. We validate the measurement's statistical and economic significance and verify its consistency with the results obtained using the large language model (i.e., GPT-4). Services are categorized as complementing product sales (e.g., maintenance and repair) or substituting product sales entirely (e.g., machine hours). Utilizing difference-in-difference techniques, we find robust evidence that manufacturers' service offerings reduce the bullwhip effect in two steps: basic complementing services decrease demand variability, whereas advanced substituting services mitigate intrafirm bullwhip. Moreover, servitization mainly minimizes demand variability through information channels, whereas increased production efficiency decreases intrafirm bullwhip. Our findings contribute to understanding manufacturers' business model innovations by demonstrating that servitization can smooth demand and mitigate intrafirm bullwhip.

History: Accepted by Karan Girotra, operations management.
Funding: This work was supported by the National Natural Science Foundation of China [Grants 71931007, 72091214] and General Research Fund by Hong Kong Research Grants Council [Grant 14505320].
Supplemental Material: The data and the online appendix are available at https://doi.org/10.1287/mnsc.2023.01026.

Keywords: bullwhip effect • servitization • textual analysis • large language model

1. Introduction

Around the globe, economies are shifting toward a service-oriented model where customers favor paying for performance outcomes rather than tangible products (Bedi 2020, Deloitte 2020). This shift has prompted manufacturers to integrate service offerings into their core operations, resulting in the "servicizing business model" (Agrawal and Bellos 2017, p. 1545) or "servicization" (Orsdemir et al. 2019, p. 674). Established manufacturers like IBM, Xerox, Caterpillar, and Rolls Royce are adopting various services to differentiate themselves in the market (Guajardo and Cohen 2018). Bedi (2020) identifies servitization as a top trend influencing industrial manufacturers. Manufacturers primarily offer two categories of services: complementing services and substituting services (Cusumano et al. 2015). Complementing services improve product functionality, such as Caterpillar's maintenance services that help customers with maintenance planning, diagnostics, and analytics to minimize downtime and optimize efficiency. Substituting services, based on complementing services, replace product ownership with direct access to product use outcomes or performance. A prominent example is Rolls Royce's "hourly billing" service, which enables airlines to purchase engine usage instead of directly purchasing engines. Many manufacturers are shifting from basic complementing services to advanced substituting services (Bakshi et al. 2015).

Manufacturers have traditionally faced challenges with the bullwhip effect, where order variance exceeds downstream sales variance, increasing production costs (Lee et al. 1997). Empirical research has focused on two key bullwhip issues: *demand variability* and *intrafirm bullwhip*. Demand variability refers to the volatility of the aggregate customer demand experienced by the manufacturers (Cachon et al. 2007, Bray and Mendelson 2012), which is also called "felt" bullwhip from downstream customers (Osadchiy et al. 2021). The intrafirm bullwhip is the deviation of production variability within the firm in response to demand variability (Lee et al. 1997, Chen et al. 2000, Croson and Donohue 2006). Both factors result in additional inventory and production costs, attracting industrial and academic attention.

Manufacturers gain accurate customer demand information and reduce haphazard ordering and excessive stocking through service provision (Fang et al. 2008). This enables them to smooth demand variability and anticipate needs. Instead of solely offering products, manufacturers can provide direct product performance, ensuring seamless outcomes (Örsdemir et al. 2019). Adjusting production and inventory based on actual demand improves efficiency and reduces product-side deviation (Örsdemir et al. 2019). Therefore, our study aims to explore how offering services alongside products stabilizes demand and mitigates intrafirm bullwhip. Empirical investigations will reveal the differential impacts of manufacturers' services.

Identifying manufacturers' services is a key challenge. To address this, we create a unique measurement of servitization using "bag-of-words" text analysis on 10-K filings from the Securities and Exchange Commission's (SEC's) Electronic Data Gathering, Analysis, and Retrieval (EDGAR) database. Our measurements are unique in that they capture both (a) the total number of services and (b) the different service categories. We obtain service offerings from 1,352 manufacturing firms 1997 to 2018. Validation tests demonstrate its accuracy in capturing services, positive correlation with service outputs, and impact on operational responses. The large language model (LLM) (i.e., GPT-4) is also used for text mining in a small 10-K sample, showing consistency with our measurement.

We employ a difference-in-difference (DID) methodology on matched samples to examine the impact of servitization on the bullwhip effects. Results show that manufacturers' service offerings progressively reduce the bullwhip effect: offering complementing services leads to a 13.14% reduction in the demand variability (i.e., smoothing demand), whereas advanced substituting services result in a 20.56% reduction in the intrafirm bullwhip (i.e., reducing distortion). These effects remain robust when considering moderating factors, using alternative techniques and samples, and conducting placebo tests. The demand-smoothing effect is stronger for firms with shorter customer cooperation durations and frequent ordering behavior, emphasizing the importance of enhanced customer information sharing. The distortion-reduction effect is more notable for firms with lower inventory turnover and in sectors with gradual depreciation, highlighting improved production efficiency as a means to alleviate intrafirm bullwhip.

Our study contributes to the field of operations management (OM) in multiple ways. We introduce an innovative measurement of manufacturers' servitization process. This study also pioneers the incorporation of textual data from 10-K filings and the usage of GPT models. Previous databases lack distinct disclosure of manufacturers' service-oriented activities, as noted by Guajardo and Cohen (2018), and existing research on servitization has been limited to small samples (Kastalli and Van Looy 2013, Guajardo et al. 2016). Our measurement expands on previous metrics, covering 1,352 U.S.-listed manufacturers from 1997 to 2018 and providing detailed service information. These attributes make it a valuable resource for future empirical investigations into servitization phenomena.

Second, this study is relevant to the empirical discourse on addressing the bullwhip effect. Existing remedies include within-firm actions like reducing lead times and batch sizes (Lee et al. 1997), as well as cross-firm strategies such as information coordination in the supply chain (Chen et al. 2000, Croson and Donohue 2006), third-party involvement (Tunca and Zhu 2018), and redefining customer bases (Osadchiy et al. 2021). Our research goes a step further by highlighting the servitization business model as an appealing solution to mitigate the bullwhip effect.

Last, this study also contributes to the understanding of service operations and servitization business models. Previous research has examined the impact of servitization on financial performance (Suarez et al. 2013, Örsdemir et al. 2019), environmental protection (Agrawal et al. 2012, Agrawal and Bellos 2017), and product quality (Guajardo et al. 2016). In contrast, our paper empirically explores the operational benefits of servitization, specifically its ability to improve supply chain efficiency by reducing the bullwhip effect. This addresses the call by Girotra and Netessine (2013, p. 539): "how can we, operations management researchers, better understand business model innovations and, more importantly, proactively help design them?"

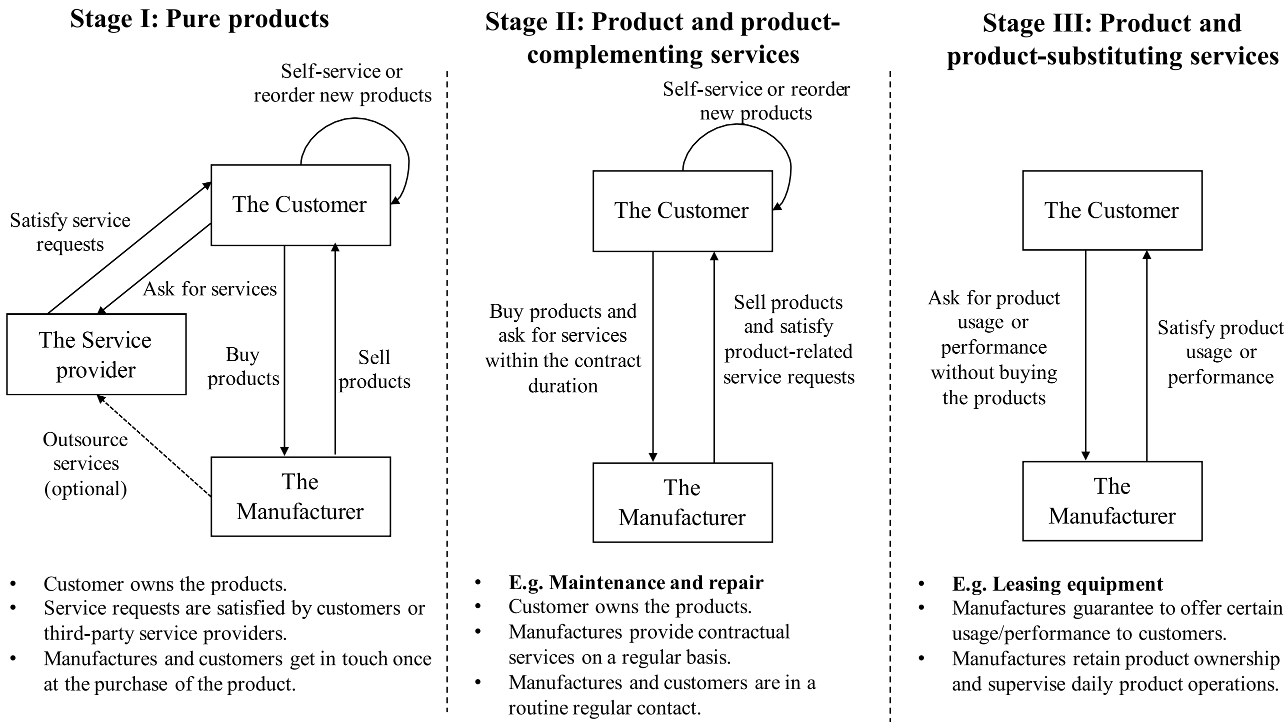
2. Research Background and Hypotheses Development

In this section, we first discuss how manufacturing firms are rapidly transitioning toward a service-based operational model, commonly referred to as servitization. Next, we propose hypotheses regarding how the service offering impacts the bullwhip issues.

2.1. The Servitization Evolution in Manufacturing

Manufacturers generally take a stepwise approach toward expanding their service portfolios from foundational service revenue streams (field service, repairs, spares, etc.) to advanced service revenue streams (performance and outcome services). Figure 1 illustrates three stages of service business and transactional relationships between manufacturers and customers. Traditional manufacturers often regard services as an

Figure 1. Evolution of Service Business Between Customers and the Manufacturing Firms



ancillary obligation that could be outsourced to third-party providers (Jain et al. 2013), as Stage I suggests. Manufacturers and customers do not maintain contact postproduct transactions. If a customer faces product failure and requires service, they may independently investigate, engage third-party providers, or reorder products from manufacturers.

Over time, as Stage II shows, manufacturers begin to assume some of the responsibilities of the services and sell contractual services directly to customers (Bakshi et al. 2015). These services, such as maintenance and repair, are offered on a regular basis or within the contract duration of an agreed contract. Customers own the products, but manufacturers can stay in touch with customers in after-sale periods. Manufacturers can help customers improve product functionality if needed before the service contract expires. Stage III illustrates the phase when manufacturers utilize their products as a means of service delivery, directly selling the usage or performance generated by the products. In this stage, manufacturers still offer customers product-complementing services as these services are the basis of the product performance (Örsdemir et al. 2019). However, customers no longer own the products and instead directly pay for the usage, functions, or outcomes derived from them (Agrawal and Bellos 2017). Manufacturers maintain ownership of the products, assume control of all product-related operations, and oversee daily usage conditions.

In this three-stage service evolution, manufacturers have migrated from selling pure products to selling product–service combos and to directly selling product performances (Bakshi et al. 2015, Agrawal and Bellos 2017, Örsdemir et al. 2019). Manufacturers who provide performance-based services in Stage III transactions have already gone through the Stage II, as performance-based services require manufacturers to fully integrate all service delivery capabilities, eliminate business and data silos, and design a road map for implementation in line with customer expectations. For example, Cusumano et al. (2015) observe that services related to Stage III transactions are provided when an industry has reached a mature phase, whereas Stage II services are merely offered as a part of the product to promote its sales.

2.2. Hypotheses Development

As a new business model, servitization has reconfigured the relationships between manufacturers and their customers and significantly changed the way manufacturing operations are designed and managed (Zhao et al. 2012, Bakshi et al. 2015, Örsdemir et al. 2019). We argue that servitization could affect manufacturers' demand variability through information sharing at both the product level and the sourcing relationship level. First, at the product level, customers rarely have a channel to communicate with the product's manufacturer after a one-time product purchase under the pure product selling context. Through product–service integration, manufacturers more frequently manage the back-end operation processes of the products such as shipping, delivery, order management, product maintenance, and customer support (Suarez et al. 2013). This back-end intervention allows the manufacturers to obtain actual product demand and control the inventory level of products and pool demands from different users (Örsdemir et al. 2019). Thus, upstream manufacturers can better anticipate and prepare for fluctuations through aggregating downstream product demands (Croson and Donohue 2006).

Second, at the sourcing relationship level, servitization increases collaboration between manufacturers and customers. Service offerings have compensatory effects on customers' purchase decisions (Guajardo et al. 2016). During the service process, manufacturers maintain their products on behalf of their customers. This compensates for the quality issue of products reduces customers' perception of manufacturers' misbehavior and running out of capacity (Bakshi et al. 2015, Guajardo et al. 2016, Liu et al. 2019). Customers with more information from the supply side will not need to overorder products and will no longer frequently change order quantities because of distrust, which alleviates the demand uncertainty. With a stable sourcing relationship and intensive information sharing, demand for a manufacturer's product will become more predictable. Besides, manufacturers can also inform customers of their inventory level and production conditions. Customers may be promoted to purchase more when they have a healthy inventory and less when the supply is tighter. Therefore, manufacturers' service offerings alleviate volatility in demand.

Hypothesis 1. *Demand variability for a manufacturing firm decreases following the manufacturer's service offerings.*

We next argue that servitization could affect manufacturers' intrafirm bullwhip through improved production efficiency at both the product level and the firm level. First, at the product level, manufacturers can enhance their production flexibility for a specific product with the demand information (e.g., the actual component needs) both from the customers and overall market during the service delivery process (Kastalli and Van Looy 2013). Manufacturers traditionally arrange their production based on demand forecasting, lead time, production flexibility, and other private information held by the decision makers (Chen et al. 2000). To avoid stockout and other supply uncertainties such as price fluctuation, manufacturers tend to err on the side of caution and produce more than is warranted by actual demand. With more accurate and complete information obtained from downstream customers' usage through services, manufacturing firms can better tune their manufacturing scheduling to satisfy customers' current and prospective needs (Lu and Lariviere 2012), and avoid irrational production decisions and surplus for specific products (Örsdemir et al. 2019). This increases production flexibility, avoids inventory pileups, and enables shorter supply time (Cachon and Olivares 2010).

Second, at the firm level, manufacturers are evolving from traditional product-oriented operations to service-oriented operations. Under the paradigm of servitization, manufacturers offer advanced services on the basis of product performance and retain product ownership (Örsdemir et al. 2019). This ownership model enables manufacturers to supervise daily product usage conditions and control comprehensive usage data. As customers compensate directly for the outcomes, usages, or functions derived from these products (Agrawal and Bellos 2017), manufacturers find it essential to integrate both production and service delivery processes seamlessly to meet performance expectations. Therefore, they are more likely to adjust their product designs and production planning in accordance with real-time demand and specific customization needs. For example, manufacturing firms are likely to extend product life span and increase product reliability to fit in service contracts (Ramdas and Randall 2008, Guajardo et al. 2016), merge product and service requirements during manufacturing, or provide highly customized services that compensate the product usage (Guajardo and Cohen 2018). These firm-level operational transformations benefit manufacturers in various ways: they can better forecast demands, optimize operations, achieve a more consistent production process, and thereby minimize the discrepancy between production variability within the firm and demand variability, termed the intrafirm bullwhip. We expect that the intrafirm bullwhip will decrease when the manufacturer provides services.

Hypothesis 2. *The intrafirm bullwhip for a manufacturing firm decreases following the manufacturer's services offerings.*

3. Data and Measurement

We focus on U.S. publicly listed manufacturing firms and assemble data from several sources. Our research team collects data on manufacturers' service offerings through text mining of the 10-K filings from the SEC EDGAR database.[1] We measure demand variability and intrafirm bullwhip effect using financial data obtained from the Compustat database. Control and moderating variables are also from the Compustat database. After merging the data, we obtain 48,352 observations from 1997 to 2018 on 5,047 unique manufacturing firms (1,352 are servitized manufacturing firms) whose two-digit Standard Industrial Classification (SIC) codes are between 20 and 39.[2]

3.1. Independent Variable: Manufacturers' Service Offerings

Conventional structured databases typically lack information on manufacturers' service offerings. We extract data on manufacturers' service offerings from the SEC EDGAR database, where a detailed narrative of a firm's business operations is mandatorily disclosed. The measurement construction process is outlined in the following steps.

Initially, the extraction of commonly offered service types by manufacturers and their frequently used keywords is facilitated through a literature review, as exemplified by Cusumano et al. (2015). Subsequently, we download business descriptions in Item 1 (Business) of the 10-K filings from the SEC EDGAR database.[3] The aggregation of 27,640 10-K filings from a total of 2,042 listed manufacturing firms spanning the period from 1997 to 2018 culminates from the adherence to specific criteria: (1) keeping only manufacturing firms with two-digit SIC codes ranging from 20 to 39 (Muthulingam et al. 2013) and a workforce exceeding 100 employees; (2) keeping Forms 10-K and Forms 10-K405 for the selected firms between fiscal years 1997 and 2018;[4] and (3) including only the first 10-K filing for the fiscal year by the firm, ensuring a minimum of 180 days between filings, and excluding amended filings (Jegadeesh and Wu 2013).

Next, we employ a bag-of-words text analysis on the unstructured textual data in 10-K filings. The bag-of-words model is a widely utilized representation method that leverages domain-specific word lists to categorize objects and extract thematic information. The underlying principle is to disregard the autocorrelation of the word (or phrase) sequences, assuming that the targeted word (or phrase) counts are sufficient statistics for quantifying extracted key points (Loughran and McDonald 2016, Büschken and Allenby 2020). Because our task is to extract objective services rather than analyze the tone, emotions, or performance from paragraphs, it is reasonable for us to assume that word order is inconsequential. We develop and validate a service word list for 13 typical manufacturers' services based on over 1,000 randomly selected 10-K filings.

Subsequently, we apply the word list to match keywords in the remaining 10-Ks. We determine that a firm offers a specific service type in a fiscal year if the business description in the 10-K for that year includes any service keywords of that type. This coding process enables us to calculate the total number of service offerings of the firm in that year (*ServiceNum*). An example of parsing services in Boeing's 10-K filings is presented in Appendix B. In the 2017 Form 10-K, Boeing describes its service businesses in several separate paragraphs with objective phrases. Because Boeing mentions keywords for eight service types, we record the number of services offered by Boeing in 2017 as eight.

Following this process, we identify 1,899 manufacturing firms offering at least one service between 1997 and 2018. The 13 service types display a balanced overall distribution and show variations across industries. Furthermore, industries such as textiles and apparel predominantly offer trade and distribution services, whereas heavy or technology-intensive industries like machinery and equipment are more likely to provide maintenance, parts and technical support, leasing, and integrated solutions. Last, we combine service data with financial data from the Compustat database using the Central Index Key identifier.[5]

3.2. Dependent Variables: Demand Variability and the Intrafirm Bullwhip

In alignment with previous studies such as Cachon et al. (2007), Moritz et al. (2022), and Osadchiy et al. (2021), we define *demand variability* (*DV*) and the *intrafirm bullwhip* (*BWE*) using Equations (1) and (2). Specifically, demand variability is gauged by the standard deviation of the first-difference demand series, which is derived from the logged quarterly cost of goods sold (COGS) series $COGS_{i,s}$ over the time window Δ. The intrafirm bullwhip is calculated based on the difference between the standard deviation of the first-difference production series $Production_{i,t}$ and that of the $COGS_{i,t}$ series over the time window Δ. The term $Inventory_{i,t}$ represents the inventory of firm i in quarter t, and $Production_{i,t}$ denotes the production series of i in quarter t, which is computed using $COGS_{i,t}$ and $Inventory_{i,t}$.[6] In subsequent analyses, we calculate both bullwhip issues over eight quarters. We retain $DV^{\Delta}_{i,t}$ and $BWE^{\Delta}_{i,t}$ in the fourth quarter of each year to represent the annual bullwhip effects:

$$DV^{\Delta}_{i,t} = Std.(\ln COGS_{i,s} - \ln COGS_{i,s-1}), \tag{1}$$

$$BWE^{\Delta}_{i,t} = Std.(\ln Production_{i,s} - \ln Production_{i,s-1}) - Std.(\ln COGS_{i,s} - \ln COGS_{i,s-1}), \tag{2}$$

where $s = t - \Delta + 1, \ldots, t$, and $Prodution_{i,t} = COGS_{i,t} + (Inventory_{i,t} - Inventory_{i,t-1})$.

3.3. Control Variables

We include a collection of control variables, following Fang et al. (2008). We first control for firm size (*Size*), measured by the logarithm of total assets, to ensure that the observed relationships between our variables of interest are not merely driven by size-related factors. To account for the influence of firm growth, we include profitability (*ROA*, return on assets) and sales growth (*Sales Growth*) as controls. We further control for research and development expenses (*R&D*) to account for the impact of firms' R&D capabilities and investments. Additionally, we incorporate cash slacks (*Slacks*) and leverage (*Leverage*) to minimize the possibility that our estimations are affected by the amount of cash-based resources and the size of debt financing. Table 1

Table 1. Summary Statistics

Panel A. Full sample

Variables	Obs.	Mean	Std. dev.	p25	p50	p75
Dependent variables						
DV	48,352	0.2779	0.3085	0.1068	0.1827	0.3247
BWE	48,352	0.1190	0.3270	−0.0079	0.0430	0.1590
Control variables						
Size	48,352	3.8360	3.2210	0.0000	3.7960	6.3170
ROA	48,352	−0.1670	7.2910	−0.0347	0.0588	0.1170
Sales Growth	48,352	0.1560	0.5470	−0.0219	0.0362	0.1870
Slacks	48,352	0.1700	0.2150	0.0098	0.0798	0.2490
Leverage	48,352	0.7260	6.3380	0.2590	0.4610	0.6550
R&D	48,352	0.2150	0.9590	0.0000	0.0153	0.0924

Panel B. Samples for 1,352 servitized firms only

	Before servitization				After servitization			
Variables	Obs.	Mean	Std. dev.	p50	Obs.	Mean	Std. dev.	p50
ServiceNum	2,291	0.0000	0.0000	0.0000	17,584	2.1210	2.4280	1.0000
DV	2,291	0.2565	0.2338	0.1844	17,584	0.1912	0.1903	0.1389
BWE	2,291	0.1170	0.2810	0.0478	17,584	0.1010	0.2570	0.0385
Size	2,291	2.4770	3.0040	0.0000	17,584	3.8320	3.5350	4.4160
ROA	2,291	−0.0198	0.3960	0.0589	17,584	0.0610	0.2600	0.0844
Sales Growth	2,291	0.1890	0.5900	0.0000	17,584	0.1260	0.3930	0.0603
Slacks	2,291	0.1610	0.2390	0.0386	17,584	0.1570	0.1840	0.0858
Leverage	2,291	0.4620	0.4380	0.4130	17,584	0.4960	0.6610	0.4710
R&D	2,291	0.2200	0.9400	0.0067	17,584	0.1020	0.4690	0.0211

Note. Obs., Observations; Std. dev., standard deviation; p25, 25th percentile, p50, median; p75, 75th percentile.

presents summary statistics for key variables. Panel A encompasses both servitized and nonservitized firms, whereas panel B summarizes key variables for servitized firms before and after the servitization period. Definitions for all variables are provided in Table A.1 of Appendix A.

4. Validation Tests for Servitization Measurement

Although it is compulsory to disclose business descriptions in 10-K filings, differences in the level of details disclosed among companies may still pose challenges to our servitization measurement. To validate the potential informativeness of the measurement as an indicator in capturing the servitization process, this section implements a multipronged approach.

4.1. Servitization Variation over Time and Across Industries

To accurately measure the degree of servitization, it is essential to first validate the effectiveness of our bag-of-words technique in capturing the relevant services mentioned in 10-K filings, as well as its variations over time and across different industries. The text-mining process inherently takes into account the time points. Before finalizing the service keywords, a stratified sampling method is employed to manually extract service-related terms from a subset of filings, categorized by industry. This approach ensures the representation of keyword variations across industries. A comparison between manually extracted terms and algorithm-generated terms follows, allowing for the identification and rectification of false positives and false negatives. This iterative process enhances the precision of service identification within the lexicon.

Firms typically group their service businesses in the descriptions, using specific phrases that make it easy for readers to extract information about services such as maintenance and installations. The case of Boeing, as depicted in Figure B.1 of Appendix B, illustrates this intuitively. The results from our bag-of-words approach closely match the reader's expectations. Moreover, business descriptions in 10-K filings generally focus on current operations and events, rather than future business plans. Consequently, our measurement of servitization is a reflective measurement of the current businesses.

The measurement shows that there has been an increasing trend since 1997, and servitization surges from the 1990s also to the early 2000s. Research and anecdotal evidence indicate that during the early 2000s, many U.S. manufacturers faced foreign competition and had strong incentives to diversify their businesses with services (Olivares and Cachon 2009). Besides, the companies identified with the highest number of service businesses correspond to certain anecdotal evidence.

For instance, Cohen et al. (2006) and Suarez et al. (2013) report that Hewlett Packard Inc. promoted its existing leasing programs in the early 2000s, specifically to maintain control over used products and avoid providing consumers with explicit incentives to return these products. Hewlett Packard is the top servitized firm identified by the measurement from 1997 to 2001. In recent years, numerous aerospace firms have announced plans to significantly grow their aftermarket revenue. This aligns with the measurement that Boeing remains the top servitized firm after 2013. Additionally, typical firms that implement servitization, such as Caterpillar, which uses data transmitted from vehicles to help make decisions optimizing performance, are also identified by our servitization measurement as top service providers in 2010.[7]

4.2. Service Output Following Servitization

Although the manufacturer's text-based servitization measurement captures service-related information in text documents, it might not fully reflect the realized benefits of these service businesses. The lack of imposed restrictions by the SEC on details in 10-K business descriptions could lead to information lacking substance. To address this, we conduct a statistical test to determine whether our servitization measurement accurately mirrors materialized service sales, a direct service business outcome. Ideally, the disclosed services in a year should positively correlate with that year's service sales, indicating genuine service business growth. This correlation can be examined by regressing the servitization measurement on contemporaneous service sales levels:

$$ServiceOutput_{i,t} = \beta_0 + \beta_1 \cdot log(ServiceNum_{i,t}) + \phi' X_{i,t} + FE + \epsilon_{i,t}, \tag{3}$$

where $ServiceOutput_{i,t}$ is the logarithm of the firm i's reported sales for its service businesses, in millions, in period t. We retrieve sales of service businesses from the Compustat Business Segment database. The term $\log(ServiceNum_{i,t})$ is the logarithm of the number of services plus one. The term $X_{i,t}$ is a collection of control variables. By including a set of fixed effects (FEs), we can evaluate the measurement's capability to capture the service development beyond common factors at both the time and industry levels. Panel A of Table 2 reports the result. The first column shows that the estimated coefficient is positive and statistically significant, indicating that a one-standard-deviation increase in the service number is associated with a 0.061-standard-deviation increase in service sales.

To assess our measurement's ability to capture gradual servitization, we analyze whether an increase in the number of services in our measurement correlates with a rise in service sales. We assign each value of $ServiceNum_{i,t}$ its own dummy variable to observe the gradual changes. The term $\mathbb{I}\{ServiceNum_{i,t} = k\}$ equals one if the number of services for firm i in year t is k and zero otherwise. Ninety-nine percent of the firms included in our sample provide 11 or fewer services. Consequently, we have constructed 11 dummy variables to represent the range of service offerings. We replace $\log(ServiceNum_{i,t})$ with these service dummies and test the gradual changes by the following regressions:

$$ServiceOutput_{i,t} = \beta_0 + \Sigma_{k=1}^{11} \beta_k \cdot \mathbb{I}\{ServiceNum_{i,t} = k\} + \phi' X_{i,t} + FE + \epsilon_{i,t}. \tag{4}$$

Column (1) in panel B of Table 2 shows the estimated coefficients increase with the increase in the number of services, indicating our measurement captures actual service business growth. These substantial effects underscore the measurement's strong link to realized service output at the firm level.[8]

4.3. Supply Chain Coordination Through Servitization

We further evaluate the validity of the servitization measurement by investigating its ability to capture improvements in customer–supplier relationships. Servitization essentially involves shifting product management duties from customers to manufacturers. As a result, service businesses should ideally act as intermediaries, promoting better coordination between suppliers and customers. If our measurement accurately represents these dynamics, it should display a positive correlation with increased risk sharing among key customers. This signifies a closer supply chain relationship when upstream firms offer services (Osadchiy et al. 2021).

To test this hypothesis, we employ the average correlation between the abnormal stock returns of manufacturers and their principal customers as an indicator of risk sharing with principal customers. Information on customer–supplier relationships is derived from the Compustat Segments Customer database.[9] Monthly security return and market return data are obtained from the Center for Research in Security Prices (CRSP) database. For each year, the risk sharing between the manufacturer and its customers (*RiskSharing*) is calculated as the average correlation of 12-month abnormal returns between manufacturers and their principal customers. We replace the dependent variable *ServiceOutput* in Equations (3) and (4) with *RiskSharing*. As shown in column (2) of Table 2, our servitization measurement exhibits a significantly positive relationship with risk sharing among principal customers, despite slight variations in the estimated coefficients. Servitization thus promotes supply chain coordination through customer risk sharing, which our measurement effectively captures.

Table 2. Measurement Validation: Service Outputs, Supply Chain Coordination, and Firm-level Responses

	Service output	Supply chain coordination	Operational responses			
Variable	(1) Service sales	(2) Risk sharing	(3) Intangible assets	(4) Manufacturing costs	(5) Inventory	(6) Production
Panel A. General changes: Service number as the independent variable						
log(*ServiceNum*)	0.159***	0.023***	0.019***	−0.015***	−0.009***	−0.010***
	(0.041)	(0.007)	(0.004)	(0.002)	(0.002)	(0.002)
Size	0.039***	0.008***	0.008***	0.004***	0.004***	0.003***
	(0.008)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
ROA	0.000**	0.121***	−0.000	0.003	0.000	−0.002
	(0.000)	(0.018)	(0.000)	(0.005)	(0.006)	(0.005)
Sales Growth	−0.023***	0.007	0.015***	0.015**	−0.008	−0.042***
	(0.006)	(0.007)	(0.002)	(0.006)	(0.005)	(0.006)
Slacks	−0.266***	0.026	−0.222***	0.125***	0.211***	0.192***
	(0.050)	(0.022)	(0.008)	(0.014)	(0.014)	(0.014)
Leverage	0.000	−0.013*	−0.000	−0.003***	−0.003	−0.003**
	(0.000)	(0.009)	(0.000)	(0.001)	(0.002)	(0.001)
R&D	0.001	0.008*	0.004**	0.011***	0.019***	0.001
	(0.003)	(0.004)	(0.002)	(0.004)	(0.004)	(0.004)
Year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Industry FEs	Yes	Yes	Yes	Yes	Yes	Yes
Observations	48,352	10,708	44,672	42,032	41,534	40,838
R^2	0.043	0.118	0.1147	0.019	0.027	0.029
Panel B. Gradual changes: Service dummy variables as the independent variables						
$\mathbb{I}\{ServiceNum = 1\}$	−0.020	−0.006	0.016**	−0.022***	−0.011**	−0.016***
	(0.037)	(0.011)	(0.007)	(0.005)	(0.005)	(0.006)
$\mathbb{I}\{ServiceNum = 2\}$	0.039	0.005	0.006	−0.029***	−0.015**	−0.021***
	(0.058)	(0.020)	(0.010)	(0.007)	(0.007)	(0.008)
$\mathbb{I}\{ServiceNum = 3\}$	0.147*	0.042***	0.018*	−0.021***	−0.006	−0.013**
	(0.087)	(0.018)	(0.010)	(0.006)	(0.006)	(0.006)
$\mathbb{I}\{ServiceNum = 4\}$	0.267**	0.015	0.019*	−0.021***	−0.010	−0.013**
	(0.116)	(0.018)	(0.011)	(0.006)	(0.007)	(0.006)
$\mathbb{I}\{ServiceNum = 5\}$	0.289***	0.045***	0.036***	−0.022***	−0.012	−0.019**
	(0.108)	(0.021)	(0.012)	(0.007)	(0.008)	(0.007)
$\mathbb{I}\{ServiceNum = 6\}$	0.457***	0.061***	0.047***	−0.036***	−0.033***	−0.026***
	(0.174)	(0.022)	(0.013)	(0.009)	(0.010)	(0.009)
$\mathbb{I}\{ServiceNum = 7\}$	0.250*	0.113***	0.052***	−0.020***	−0.006	−0.014
	(0.146)	(0.037)	(0.015)	(0.007)	(0.009)	(0.009)
$\mathbb{I}\{ServiceNum = 8\}$	0.569***	0.040	0.068***	−0.026**	−0.025*	−0.009
	(0.217)	(0.037)	(0.019)	(0.013)	(0.013)	(0.013)
$\mathbb{I}\{ServiceNum = 9\}$	0.343	0.061*	0.053**	−0.024*	−0.028	−0.019
	(0.266)	(0.042)	(0.025)	(0.014)	(0.018)	(0.015)
$\mathbb{I}\{ServiceNum = 10\}$	1.216*	0.004	0.104***	0.006	−0.051*	0.003
	(0.705)	(0.041)	(0.038)	(0.020)	(0.031)	(0.020)
$\mathbb{I}\{ServiceNum = 11\}$	1.579*	−0.108	−0.016	−0.068	0.069	−0.030
	(0.940)	(0.089)	(0.041)	(0.055)	(0.027)	(0.029)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Industry FEs	Yes	Yes	Yes	Yes	Yes	Yes
Observations	48,352	10,708	44,672	42,032	41,534	40,838
R^2	0.046	0.119	0.148	0.019	0.027	0.029

Note. Ordinary least squares (OLS) estimates with robust standard errors clustered by the firm are in parentheses.
*$p < 0.1$, **$p < 0.5$, and ***$p < 0.01$ using two-tailed tests.

4.4. Firm-Level Operational Responses Toward Servitization

If the measurement accurately captures the servitization process, it should be positively related to the operational processes typically carried out in response to the service transformations. Existing research highlights services as intangible, immediately consumed, and less storable (Suarez et al. 2013, Cusumano et al. 2015). Thus, higher servitization levels should prompt more intangible asset investment. Moreover, for effective service operations (e.g., maintenance, leases), heightened servitization should coincide with reduced manufacturing efforts, leading to lower stockpiling and fewer product sales.

To economically validate the operational responses to our servitization measurement, we replace the dependent variable *ServiceOutput* in Equations (3) and (4) with four operational indicators: *Intangible Assets* (intangible assets over total assets), *Manufacturing Costs* (natural logarithm difference of the cost of goods sold series scaled by total sales), *Inventory* (natural logarithm difference of the inventory series scaled by total assets), and *Production* (natural logarithm difference of the production series). Columns (3)–(6) of panel A in Table 2 shows that the number of services is positively associated with intangible assets and negatively associated with COGS, inventory, and production. Moreover, panel B reveals that a one-by-one increase in the number of services correlates with a rise in the share of intangible assets and a decrease in COGS and production. The inventory level also declines as the number of services increases. These findings confirm that our servitization measurement accurately captures the key operational responses to servitization transformations.

5. Does Servitization Reduce the Bullwhip Effect?

In this section, we first explore the association between the number of services and the two bullwhip issues, then use DID techniques to support causal explanations, and finally explore the differential impacts for the two service categories.

5.1. The Incremental Effects of Servitization

We examine the association between service numbers and demand variability or the intrafirm bullwhip in multiple ways. Scatter plots of the original data reveal a general decline in both demand variability and intrafirm bullwhip as the number of services increases across most manufacturing sectors. We further compare the mean values of both bullwhip indicators before and after service provision using t-tests. These analyses consistently show a significant decrease in demand variability and intrafirm bullwhip once manufacturers introduced services.

Subsequently, an exploration of the connection between a manufacturer's count of service offerings and its demand variability, along with the intrafirm bullwhip, is undertaken through Equations (5) and (6). Each value of $ServiceNum_{i,t}$ is assigned an individual dummy variable, thereby facilitating the observation of gradual shifts in *DV* and *BWE* corresponding to variations in the number of services. The binary indicator $\mathbb{I}\{ServiceNum_{i,t} = k\}$ assumes a value of one when $ServiceNum_{i,t}$ equals k, and zero otherwise. The vector $X_{i,t}$ comprises a set of control variables. Both time- and industry-fixed effects are controlled.[10]

When services are first introduced, demand variability immediately decreases, and as more services are provided, demand variability continues to decline at a fairly steady rate. However, when the service level is relatively low (e.g., with only one or two services), the intrafirm bullwhip does not significantly decrease. It is only when the number of services provided reaches a certain threshold that the intrafirm bullwhip starts to decrease significantly:[11]

$$DV_{i,t} = \beta_0 + \Sigma_{k=1}^{11}\beta_k \cdot \mathbb{I}\{ServiceNum_{i,t} = k\} + \phi' X_{i,t} + FE + \epsilon_{i,t}, \tag{5}$$

$$BWE_{i,t} = \beta_0 + \Sigma_{k=1}^{11}\beta_k \cdot \mathbb{I}\{ServiceNum_{i,t} = k\} + \phi' X_{i,t} + FE + \epsilon_{i,t}. \tag{6}$$

We extend our investigation to reveal these notable observations, considering that variations in the impact of servitization on demand variability and the intrafirm bullwhip effect could be attributed to the specific characteristics of services offered at different stages. This aspect will be explored in greater detail in the upcoming section.

5.2. Difference-in-Difference Estimations with Matched Samples

The findings from model-free analyses and ordinary least squares (OLS) estimates, although insightful, are not sufficient on their own to establish causal interpretations, as they may overlook interference from other time-invariant factors. To address potential alternative explanations, we employ DID techniques to ascertain the impact of manufacturers' service offerings. We differentiate between treatment and control groups using the *ServiceTreat* dummy variable, which equals one for a treatment manufacturer that has offered at least one service from the time it begins disclosing 10-K filings in the SEC EDGAR database until the end of the sample period in 2018 (referred to as a "servitized manufacturer") and zero for a manufacturer that never offers any services before the end of the sample period (referred to as a "nonservitized manufacturer").

To ensure the comparability of the two groups of observations, we employ a coarsened exact matching

(CEM) technique to match the treatment group of servitized manufacturers with a pseudo control group of nonservitized manufacturers that share similar covariates (Iacus et al. 2012).[12] We perform separate matching for demand variability and the intrafirm bullwhip. A many-to-many matching strategy is utilized, allowing each treatment observation to be matched with multiple control observations. Before matching the sample, pretreatment periods for treatment firms are excluded from the sample to prevent their use as control observations. We match for the fiscal year to account for unobservable temporal trends and match for the two-digit SIC industry code to control for the influence of industry on service offerings.[13] Additionally, we match based on *Size*, *Sales Growth*, and prematched values of the bullwhip effect corresponding to the 10th, 25th, 50th, 75th, and 90th percentiles. Freedman–Diaconis rules are employed to ensure the distribution of the matched controls closely resembles that of the treatments (Iacus et al. 2012). After matching several controls for each treatment, we randomly remove control observations to ensure that only one control observation is selected for each treatment observation. Unmatched observations are excluded from the analysis. The matched control observations shows no significant difference with the treatment observations on matching variables.[14]

For demand variability, 8,886 treatment observations from 1,276 treatment firms are matched to 8,886 control observations from 2,433 control firms. For the intrafirm bullwhip, 7,569 treatment observations from 1,256 treatment firms are matched to 7,569 control observations from 2,210 control firms. In line with literature such as Gallino et al. (2017), we employ staggered difference-in-difference specifications in Equations (7) and (8) to identify the changes in demand variability and the intrafirm bullwhip before and after manufacturers' service offerings. The term $ServiceTreatPost_{it}$ equals one if the fiscal year t is equal to or later than the year in which manufacturer i begins to provide services, and zero otherwise:

$$DV_{i,t} = \beta_0 + \beta_1 \cdot ServiceTreatPost_{i,t} + \phi' X_{i,t} + FE + \epsilon_{i,t}, \tag{7}$$

$$BWE_{i,t} = \beta_0 + \beta_1 \cdot ServiceTreatPost_{i,t} + \phi' X_{i,t} + FE + \epsilon_{i,t}. \tag{8}$$

Table 3 displays the results of the DID estimates using different fixed effects. Columns (1)–(3) demonstrate that demand variability significantly decreases in all specifications, supporting Hypothesis 1. To illustrate the economic magnitude, we quantify the impact using the mean value of demand variability in the preservitization period for the matched sample (0.2283). We find in the full model in column (4) that demand variability decreases by 13.58% ($\beta = -0.031$, mean = 0.2283) following manufacturers' service offerings. Columns (5)–(8) indicate that the intrafirm bullwhip consistently decreases after the introduction of services. However, it does not reach statistical significance, which does not support Hypothesis 2. Although no statistically significant results

Table 3. Difference-in-Difference Estimates with Matched Groups

Variable	(1) *DV*	(2) *DV*	(3) *DV*	(4) *DV*	(5) *BWE*	(6) *BWE*	(7) *BWE*	(8) *BWE*
ServiceTreatPost	−0.034***	−0.031***	−0.034***	−0.031***	−0.006	−0.005	−0.008	−0.006
	(0.004)	(0.004)	(0.004)	(0.004)	(0.007)	(0.007)	(0.007)	(0.007)
Size	−0.016***	−0.021***	−0.015***	−0.020***	−0.008***	−0.010***	−0.008***	−0.009***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
ROA	−0.006**	−0.006**	−0.006**	−0.006**	−0.034*	−0.031*	−0.022	−0.020
	(0.003)	(0.003)	(0.003)	(0.003)	(0.017)	(0.017)	(0.016)	(0.016)
Sales Growth	0.015***	0.017***	0.013***	0.016***	0.000	0.000	−0.001	−0.001
	(0.005)	(0.005)	(0.005)	(0.005)	(0.007)	(0.007)	(0.006)	(0.007)
Slacks	0.107***	0.065***	0.084***	0.044***	0.080***	0.065***	0.050***	0.038**
	(0.012)	(0.013)	(0.013)	(0.013)	(0.018)	(0.019)	(0.018)	(0.019)
Leverage	0.001	0.001	0.001	0.001	−0.023**	−0.023**	−0.017*	−0.016*
	(0.001)	(0.000)	(0.001)	(0.001)	(0.011)	(0.011)	(0.009)	(0.009)
R&D	0.029***	0.030***	0.027***	0.029***	−0.017**	−0.016**	−0.012*	−0.012*
	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)
Year FEs	No	Yes	No	Yes	No	Yes	No	Yes
Industry FEs	No	No	Yes	Yes	No	No	Yes	Yes
Observations	17,772	17,772	17,772	17,772	15,138	15,138	15,138	15,138
R^2	0.108	0.129	0.124	0.145	0.014	0.018	0.029	0.033

Note. OLS estimates with robust standard errors clustered by the firm are in parentheses.
$^*p < 0.1$, $^{**}p < 0.5$, and $^{***}p < 0.01$ using two-tailed tests.

Table 4. Two Service Categories, Definitions, Typical Service Types, and References

Categories	Definitions	Typical service types	References
Complementing services	Services that are complementary with the purchase of products	Distribution services, procurement and purchasing, merchandise installation and assembly, technical and spare part support, maintenance services, commissioning services, certification and testing services, customization and R&D services, solutions, system integration, digital and streaming services, etc.	Roels et al. (2010), Suarez et al. (2013), Guajardo et al. (2016).
Substituting services	Services that replace the purchase of the products and directly sell the product usage or performance	Rentals, leasing businesses, performance-based contracts, software as a service, fee-per-use services, power-by-the-hour contracts, recycling services, process management services, etc.	Kim et al. (2007), Roels et al. (2010), Zhao et al. (2012), Bakshi et al. (2015).

on intrafirm bullwhip are found in DID specifications, the model-free and OLS estimates in Section 5 and the negative coefficients of DID specifications consistently reveal a negative association between manufacturers' service offerings and the intrafirm bullwhip. In the next section, we investigate further to determine the specific factors that contribute to the reduction in intrafirm bullwhip.

5.3. Puzzle Solving: What Causes the Reduction of the Intrafirm Bullwhip?

As discussed in Section 2, the fundamental difference between Stage II and Stage III of servitization lies in the dependency of services on the purchase of products (Suarez et al. 2013, Bakshi et al. 2015, Cusumano et al. 2015, Guajardo and Cohen 2018). Stage II services, or complementing services, are contractual services that facilitate product sales by regularly activating or enhancing product functionality. Stage III services, or product-substituting services, build upon complementing services but replace the need for purchasing products by directly offering the outcomes or performances resulting from product use. Table 4 provides definitions and examples for the two service categories, as outlined by Cusumano et al. (2015). The distinct stages of manufacturers offering the two service categories present an opportunity to differentiate the impact of substituting services from that of complementing services. The servitization measurement generated from text mining in 10-K filings also indicates that complementing services outnumber substituting services.[15]

Consequently, we introduce two dummy variables, $ComSerTreatPost_{i,t}$ and $SubSerTreatPost_{i,t}$, which respectively indicate whether firm i has provided complementing services and substituting services in year t. As a manufacturer typically offers complementing services when it begins to offer substituting services (Bakshi et al. 2015), we observe in our data set that when *SubSerTreatPost* equals one, *ComSerTreatPost* equals one as well.[16] Based on these two service variables, we estimate two-step DID specifications for demand variability and intrafirm bullwhip in Equations (9) and (10). The coefficient β_1 captures the effect of providing complementing services, whereas the coefficient β_2 captures the incremental effect of providing substituting services:

$$DV_{i,t} = \beta_0 + \beta_1 \cdot ComSerTreatPost_{i,t} + \beta_2 SubSerTreatPost_{i,t} + \phi' X_{i,t} + FE + \epsilon_{i,t}, \tag{9}$$

$$BWE_{i,t} = \beta_0 + \beta_1 \cdot ComSerTreatPost_{i,t} + \beta_2 SubSerTreatPost_{i,t} + \phi' X_{i,t} + FE + \epsilon_{i,t}. \tag{10}$$

Table 5 presents the results, which partially confirm our predictions. Among the two interaction terms, columns (1)–(4) reveal that only the coefficient of *ComSerTreatPost* is statistically significant. This suggests that demand variability decreases following the introduction of complementing services but does not experience further reduction upon the offering of substituting services. The decline in demand variability because of complementing services is approximately the same level (13.14%, $\beta = -0.030$, mean = 0.2283) as that resulting from overall service offerings in Table 3. This could be attributed to the fact that, in comparison with complementing services, substituting services do not engender additional customer-side cultural transformation or further supplier-customer information exchange. Customers have acclimated to purchasing

Table 5. Different Impacts of Two Service Categories

Variable	(1) *DV*	(2) *DV*	(3) *DV*	(4) *DV*	(5) *BWE*	(6) *BWE*	(7) *BWE*	(8) *BWE*
ComSerTreatPost	−0.029***	−0.030***	−0.029***	−0.030***	0.010	0.009	0.009	0.008
	(0.006)	(0.006)	(0.006)	(0.006)	(0.011)	(0.011)	(0.011)	(0.011)
SubSerTreatPost	−0.008	−0.001	−0.009	−0.001	−0.026**	−0.024**	−0.027**	−0.025**
	(0.006)	(0.006)	(0.006)	(0.006)	(0.011)	(0.011)	(0.011)	(0.011)
Size	−0.016***	−0.021***	−0.015***	−0.020***	−0.008***	−0.010***	−0.007***	−0.009***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
ROA	−0.006**	−0.006**	−0.006**	−0.006**	−0.034*	−0.031*	−0.023	−0.020
	(0.003)	(0.003)	(0.003)	(0.003)	(0.017)	(0.017)	(0.016)	(0.016)
Sales Growth	0.015***	0.017***	0.013***	0.016***	0.000	−0.000	−0.002	−0.002
	(0.005)	(0.005)	(0.005)	(0.005)	(0.007)	(0.007)	(0.006)	(0.007)
Slacks	0.106***	0.065***	0.083***	0.044***	0.077***	0.063***	0.048***	0.036*
	(0.012)	(0.013)	(0.013)	(0.013)	(0.018)	(0.019)	(0.018)	(0.019)
Leverage	0.001	0.001	0.001	0.001	−0.024**	−0.023**	−0.017**	−0.016*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.011)	(0.011)	(0.009)	(0.009)
R&D	0.029***	0.030***	0.027***	0.029***	−0.017**	−0.016**	−0.012*	−0.012*
	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)
Year FEs	No	Yes	No	Yes	No	Yes	No	Yes
Industry FEs	No	No	Yes	Yes	No	No	Yes	Yes
Observations	17,772	17,772	17,772	17,772	15,138	15,138	15,138	15,138
R^2	0.108	0.129	0.124	0.145	0.015	0.019	0.030	0.033

Note. OLS estimates with robust standard errors clustered by the firm are in parentheses.
*$p < 0.1$, **$p < 0.5$, and ***$p < 0.01$ using two-tailed tests.

services and no longer inquire about implementation specifics from the manufacturer during the product operation process, but rather only request outcomes at the conclusion of the service agreement. Consequently, their ordering behavior does not undergo significant changes following the offering of substituting services. As a result, no incremental reduction in demand variability is observed.

For comparison, columns (5)–(8) reveal that statistical significance is attained only for *SubSerTreatPost*, suggesting that the intrafirm bullwhip would not decrease following the introduction of complementing services, but would ultimately decrease upon the provision of substituting services. The full model in column (6) indicates that the intrafirm bullwhip would decrease by 20.56% ($\beta = -0.025$) after offering substituting services, compared with the mean value of the intrafirm bullwhip in the preservitization period for the matched sample (mean = 0.1216). These findings demonstrate that substituting services contributes to the reduction of intrafirm bullwhip, addressing the puzzle. This can be ascribed to the effects of an integrative service transformation and product efficiency associated with the provision of substituting services.

Two key insights emerge by comparing Tables 3 and 5. The two service categories have distinct focuses on mitigating demand variability and the intrafirm bullwhip. Complementing services primarily facilitate information sharing to reduce demand variability. In contrast, substituting services enable manufacturers to retain product ownership and improve production efficiency, thereby primarily playing a distortion-reduction role in diminishing the intrafirm bullwhip effect. This is also consistent with the insight in Table 3 that although the servitizing business model can immediately reduce demand variability, it takes more advanced services to reduce the intrafirm bullwhip.

To sum up, transitioning from product-centric to service-oriented businesses allows manufacturers to gradually address bullwhip challenges in two stages. In the first stage, manufacturers begin offering basic services that complement their products. This enhances direct information sharing between customers and manufacturers, reducing uncertainties in customer ordering behavior and subsequently lowering demand variability. Baines and Lightfoot (2013, pp. 93–94) aptly describe this phenomenon: "quite often the manufacturer can influence the particular item of equipment being deployed on a contract. … Over this time, the revenue to the manufacturing enterprise will be relatively reliable and predictable." However, during this stage, manufacturers have not yet implemented a sufficient number of service-oriented deployments within their firms. Consequently, the intrafirm bullwhip effect does not decrease immediately following the introduction of complementing services.

In the second stage, manufacturers progress toward offering more advanced services that supplant product purchases. This shift renders manufacturers fully accountable for the products' outcomes, prompting a deeper transformation of their internal processes into service-oriented operations. For instance, manufacturers providing advanced services develop service-centric Enterprise Resource Planning (ERP) systems and demand prediction techniques. These strategies help manufacturers oversee daily product operations, coordinate production and service delivery with customer information, and ensure optimal outcomes for the service agreement. As a result, substituting services assist manufacturers in better aligning their production with service demands, leading to a reduction in the intrafirm bullwhip effect.[17]

5.4. Additional Analyses and Robustness Tests

To validate that the DID estimates are not influenced by ex ante trends in demand variability and the intrafirm bullwhip effect prior to the introduction of service offerings, we assess the parallel trends for DID results based on the approach proposed by Gallino et al. (2017). Our findings support the parallel trend assumption.

Furthermore, to mitigate potential endogeneity issues because of omitted variables that might concurrently affect service characteristics and demand/production variability, we employ Bartik's instrument variables for the three fundamental variables: *ServiceTreatPost*, *ComTreatPost*, and *SubTreatPost*. Through two-stage least squares estimations, we demonstrate that our primary results remain consistent.

Last, to ensure our matching process hasn't produced results unique to the employed matching techniques, we perform a sequence of randomized simulation-based placebo tests on the primary three regressions. The outcome of these simulation tests confirms that the observed effects are not merely coincidental and do not hinge solely on model selections.[18]

6. Mechanisms

This section delves into the fundamental mechanisms that underlie the demand-smoothing and bullwhip-reduction effects of services. In order to test these mechanisms, we utilize several moderating variables as proxies for the economic channels and augment the DID equations with interaction terms.

6.1. Demand-Smoothing Channel: Information Sharing with Customers

Service businesses establish connections between manufacturers and customers for product maintenance and service interactions. Efficient information sharing through services is crucial for new customers who reorder erratically to avoid stockouts. However, as the relationship between customers and manufacturers develops, the ordering process becomes more routinized, reducing the impact of servitization on demand fluctuations. To measure information sharing, we use customer relationships and ordering frequency as proxies. The relationship duration of a firm's customer is the number of years between the initiation of the supplier-customer relationship and the most recent year of contracting. The term $ShortRelation_{i,t}$ is a dummy variable that equals one if the average duration of firm i's customer relationships is shorter than the sample median in year t and zero otherwise. The term $FrequentOrdering_{i,t}$ is a dummy variable that equals one if the average frequency of firm i's customer ordering is greater than the sample median in year t and zero otherwise.

As shown in columns (1) and (3) of Table 6, the analysis demonstrates that the demand smoothing effect of servitization is more pronounced for firms that have shorter customer relationships ($ShortRelation = 1$) and whose customers have higher reordering frequencies ($FrequentOrdering = 1$). Customers with shorter relationships and frequent reordering patterns may have a limited understanding of the manufacturer's production situation. The results indicate that firms with a higher proportion of such customers would benefit more from servitization as a means of reducing demand variability. However, relying solely on the information channel is insufficient to address the intrafirm bullwhip effect. Therefore, a combination of adjustments on both the customer and production sides is necessary, which we explore further in the following subsection.

6.2. Bullwhip-Reduction Channel: Improved Production Efficiency

Substituting services enable manufacturers to retain control over product ownership and operation, improving downtime utilization and inventory efficiency. To assess whether firms enhance product efficiency through servitization, we introduce an inventory turnover–related moderating variable. We investigate whether firms with lower turnover achieve greater bullwhip reduction with service offerings. The inventory turnover is a firm's COGS divided by its total inventories. The term $LowTurnover_{i,t}$ is a dummy variable that equals one if firm i's inventory turnover is lower than the sample median in year t and zero otherwise. In Table 6, columns (5) and (6) indicate stronger intrafirm bullwhip reduction for substituting services in firms with low inventory turnover ($LowTurnover = 1$). The results suggest service businesses optimize product life cycles, reducing the need for excess stock, and thus supporting improved production efficiency.

We also use another variable related to the product life cycles to verify the production efficiency channel. A product with a long depreciation period naturally has longer life cycles and therefore has longer service time and opportunities than a product with fast depreciation. We define fast-depreciation industries as industries whose SIC codes are between 20 and 34 (including

Table 6. Channels for Demand Smoothing and Intrafirm Bullwhip Reduction

	Information sharing				Improved production efficiency			
	Customer relationship		Ordering frequency		Inventory turnover		Depreciation rate	
Variable	(1) *DV*	(2) *BWE*	(3) *DV*	(4) *BWE*	(5) *DV*	(6) *BWE*	(7) *DV*	(8) *BWE*
ComTreatPost	−0.003 (0.009)	−0.012 (0.015)	−0.007 (0.008)	0.001 (0.016)	−0.014* (0.008)	−0.008 (0.010)	−0.031*** (0.010)	−0.011 (0.014)
SubTreatPost	−0.022** (0.009)	−0.012 (0.016)	−0.013 (0.008)	−0.029* (0.016)	−0.002 (0.008)	0.006 (0.011)	−0.006 (0.011)	0.006 (0.015)
ShortRelation	0.015** (0.006)	0.003 (0.011)						
ComTreatPost × *ShortRelation*	−0.029** (0.011)	0.040 (0.026)						
SubTreatPost × *ShortRelation*	0.032*** (0.012)	−0.032 (0.026)						
FrequentOrdering			0.018*** (0.006)	−0.002 (0.010)				
ComTreatPost × *FrequentOrdering*			−0.016* (0.010)	0.002 (0.019)				
SubTreatPost × *FrequentOrdering*			0.008 (0.010)	0.015 (0.020)				
LowTurnover					0.024*** (0.005)	0.089*** (0.009)		
ComTreatPost × *LowTurnover*					−0.010 (0.010)	0.012 (0.018)		
SubTreatPost × *LowTurnover*					−0.001 (0.010)	−0.039** (0.019)		
ComTreatPost × *SlowDepreciation*							0.003 (0.012)	0.031 (0.020)
SubTreatPost × *SlowDepreciation*							0.007 (0.013)	−0.049** (0.021)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	9,340	7,922	9,340	7,922	17,245	14,728	17,772	15,138
R^2	0.163	0.043	0.162	0.042	0.175	0.062	0.145	0.034

Notes. OLS estimates with robust standard errors clustered by the firms are in parentheses. The control variables align with the main effects.
$^*p < 0.1$, $^{**}p < 0.5$, and $^{***}p < 0.01$ using two-tailed tests.

consumer goods such as food and apparel), and define slow-depreciation industries as industries whose SIC codes are between 35 and 38 (including industrial goods such as industrial machinery, electronic equipment, and transportation equipment). The term $SlowDepreciation_{i,t}$ is a dummy variable that equals one if firm i's SIC code in year t is between 35 and 38. Columns (7) and (8) in Table 6 show that the intrafirm bullwhip reduces more in slow-depreciation industries ($SlowDepreciation = 1$) than in high-depreciation industries, whereas there is no significant difference for a reduction in demand variability. This further indicates that service businesses provide a way to make full use of the products during their life cycles, verifying the channel of increasing production efficiency for servitized firms. The confluence of the information-sharing channel and the enhanced production efficiency channel contributes to the reduction of the intrafirm bullwhip effect. This mechanism aligns with anecdotal evidence reported by Hellenic Shipping News Worldwide (2022), which states, "A combination of the shift back to services and the rationalization of consumer spending created an opposite 'bullwhip effect' of self-reinforcing inventory moderation across the supply chain."

7. Discussion on LLM-Based Text Mining

In accordance with the current trend of using large language models in financial filings, we utilize a small sample to showcase the capability of a large language model (i.e., GPT-4) in identifying servitization in 10-K filings. A structured road map has then been provided to outline the procedure of employing large language models in measurement construction.[19] The approach to constructing measurement using large language models comprises four key steps: *context definition*, *model selection*, *prompt engineering*, and *measurement evaluation*:

1. *Context definition*. The goal is to identify servitization in 10-K filings by extracting 13 distinct services. A query is presented to the ChatGPT interface, seeking advice on locating services in 10-K filings. ChatGPT suggests sourcing from the "Business" section of the 10-K filing, aligning with prior techniques that employed the bag-of-words approach.

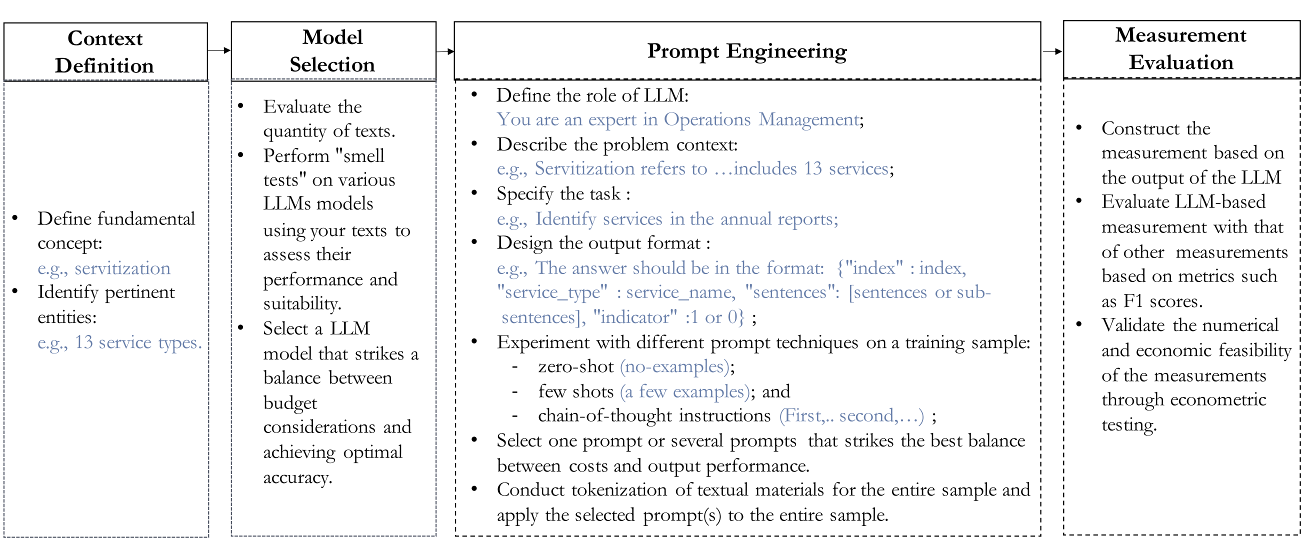
2. *Model selection*. Given the domain-specific nature of the task and the complexity of the sample, GPT-4 is selected for its superior ability to detect servitization details (model = "gpt-4"). It was deployed to analyze texts from seven firms spanning 22 years, demonstrating its capability in service identification. These firms were chosen for their industry diversity and abundant content in their 10-K filings.

3. *Prompt engineering*. To summarize servitization semantically in 10-K filings, it is crucial to frame questions that unlock GPT's potential in this domain, termed "prompt engineering." Guided by existing literature (Terwiesch 2023), the role and tasks for GPT are established by inputting "*You are a researcher in operations management and you need to identify servitization in annual reports.*" Thirteen services are then outlined with a specified output format. Finally, we zero-shot prompt[20] with chain-of-thought instructions in the following manner: "*If there is a sentence or subsentence related to any service provided by the company, that service is included and the indicator is 1. Otherwise, the indicator is 0.*" Next, all 10-K sample texts are segmented into smaller units through tokenization, facilitating the feeding of multiword tokens to GPT. The GPT application programming interface (API) is then used to process each 10-K text annually for every firm. A temperature setting of zero ensured objective and reproducible outputs. After processing, services offered by each firm annually are discerned and categorized as complementing or substituting services.

4. *Measurement evaluation*. Last, the performance of large language models in service classification is evaluated. We compare the LLM-based approach with the well-established bag-of-words technique, considering three key factors: measurement accuracy, speed of service identification, and the advantages and disadvantages of using GPT for text mining compared with traditional word-centric methods. Metrics like precision, recall, and F1 score are employed to determine the GPT-based measurement's predictive accuracy (Gao et al. 2022). The values of these metrics range from 0.73 to 0.86, suggesting the GPT-based measurements offer commendable classification efficacy for complementing and substituting services in juxtaposition with the word-based methodology. This accuracy exceeded results from similar experiments that discern cyber attacks within smart contracts (David et al. 2023).[21] The current study chooses to narrow its focus, emphasizing the method's feasibility through selected instances. In the Online Appendix B, the last column of Table OA3 showcases examples of complementing and substituting services identified by GPT. From the presented samples, it is evident that most categories align with the identifications from the bag-of-words method.

A structured road map is depicted in Figure 2, which outlines four key steps for the utility of LLMs in

Figure 2. (Color online) Measurement Construction Road Map Using Large Language Models



interpreting textual data: context definition, model selection, prompt engineering, and measurement evaluation. Among these, the prompt engineering is the core procedure, as effectively defining the context and task to LLMs enhances its inference capability in specific fields.

8. Conclusion

This study examines the rising servitization trend—as manufacturers shift from products to combined product–service offerings—for its potential to mitigate the bullwhip effect, an ongoing challenge since the 1960s (Kim et al. 2007, Bakshi et al. 2015, Guajardo and Cohen 2018). We employ bag-of-words text mining on SEC EDGAR 10-K filings and construct a data set comprising service categories for U.S.-listed firms. The servitization measurements are validated through multiple approaches. We then apply the classification method proposed by Cusumano et al. (2015) to differentiate how complementing and substituting services impact the two aspects of the bullwhip effect. The empirical findings indicate that complementing services are necessary for demand smoothing, whereas substituting services are necessary for reducing intrafirm bullwhip. Moreover, we reveal distinct mechanisms of different service categories in addressing bullwhip-related issues. Information sharing is crucial to alleviate demand variability, particularly for customers with shorter relationships and higher ordering frequencies. Meanwhile, substituting services reduces the intrafirm bullwhip effect by enhancing production efficiency, especially for firms with lower inventory turnover and those in industries with slower depreciation rates.

This study makes an important contribution to the long-standing OM literature on servitization. Despite the topic's importance, prior work exploring the impact of servitization is mainly based on analytic modeling (e.g., Guajardo and Cohen 2018) or relies on survey/case evidence (e.g., Kastalli and Van Looy 2013, Guajardo et al. 2016). Our paper builds upon these earlier efforts by leveraging 10-K filings and employing the bag-of-words text mining technique to measure servitization. This measurement allows for easy application to a large sample of firms over time, further extending and complementing existing studies.

This study has practical implications for the manufacturing sector. Specifically, we emphasize the importance of transitioning manufacturing firms toward service-oriented business models with a refined understanding of the crucial services for these firms. Complementing services enhance product functionality and facilitates sales, whereas substituting services require advanced capabilities and internal transformation. By incorporating distinct service categories based on their operational circumstances and objectives, manufacturers can effectively alleviate costs associated with high demand variability or unstable production and inventory fluctuations.

Understanding the benefits of demand stabilization and bullwhip reduction from servitization can provide managers with insights into operational shifts when incorporating service businesses, even if these benefits do not result from explicit managerial decisions. Additionally, comprehending the effects of demand variability and intrafirm bullwhip dynamics can help managers strategically manage operational factors and boost productivity. Through effective communication and information exchange with customer firms, manufacturers can gain direct insights into customer requirements and product quality, which can positively influence their operational and production strategies. These insights complement the extensively studied financial outcomes of servitization.

Acknowledgments

The authors acknowledge the editorial team's efforts in undertaking the review process and the anonymous reviewers' valuable comments in improving the quality of the paper. J. Wu acknowledges the funding support from GRF 14505320 offered by the Hong Kong Research Grants Council. S. Jiang acknowledges the funding support received from Grant 72091214, and Z. Jiang acknowledges the funding support received from Grant 71931007, both offered by the National Natural Science Foundation of China. This research was also partially supported by the Laboratory for AI-Powered Financial Technologies.

Appendix A. Variable Description and Data Source

Table A.1 presents the description, measurement, and data sources of the independent variables, controls, and moderating variables.

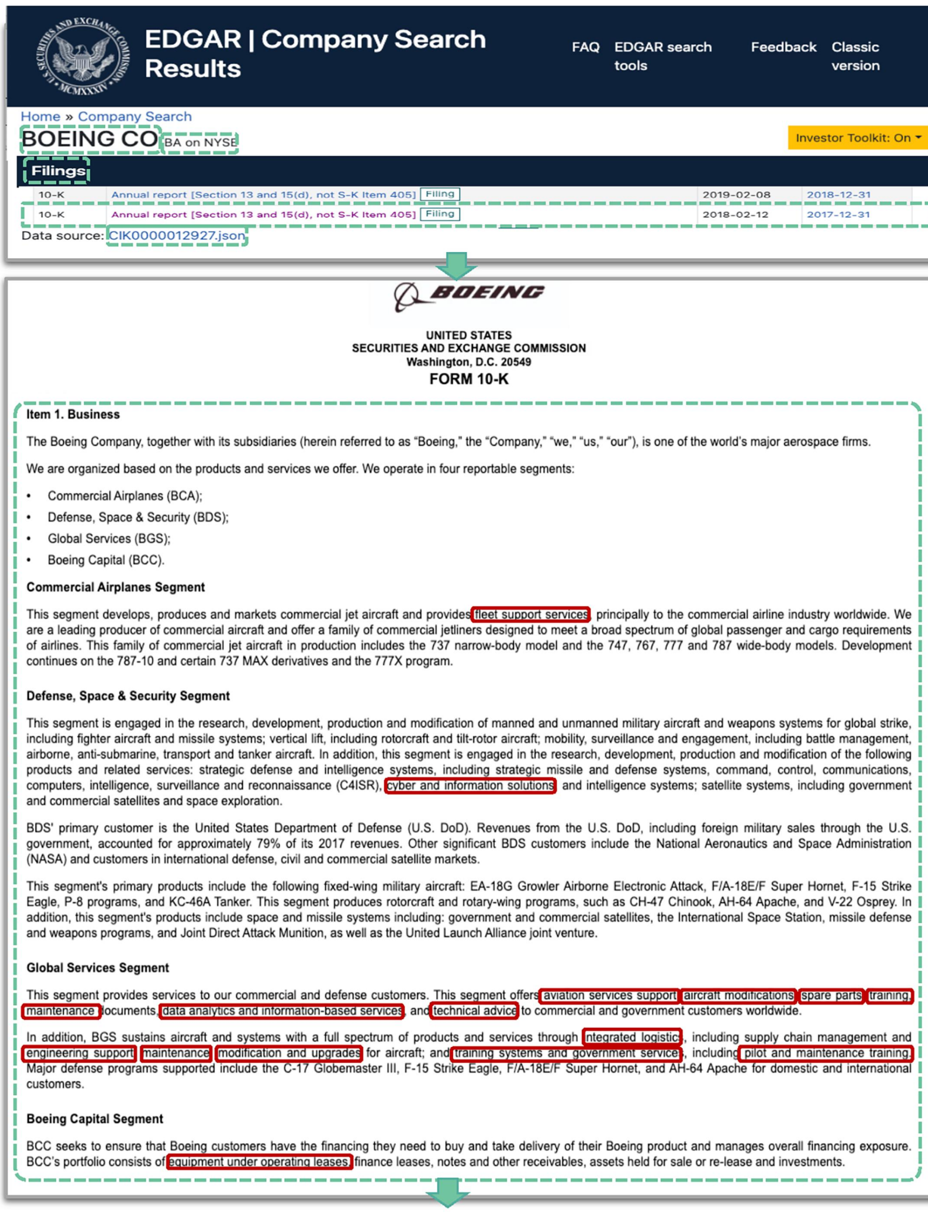
Table A.1. Variable Descriptions

Variable	Measurement	Data source
Independent variables		
$ServiceNum_{i,t}$	Number of services offered by firm i in year t	SEC EDGAR 10-K filings
$ServiceTreatPost_{i,t}$	An indicator that equals 1 if firm i offers services in the year t and equals 0 otherwise	SEC EDGAR 10-K filings
$CompTreatPost_{i,t}$	An indicator equals 1 if firm i has offered complementing services in year t and equals 0 otherwise	SEC EDGAR 10-K filings
$SubTreatPost_{i,t}$	An indicator that equals 1 if firm i has offered substituting services in year t and equals 0 otherwise	SEC EDGAR 10-K filings
Control variables		
$Size_{i,t}$	Logarithm of firm i's total assets in year t (in millions of dollars)	Compustat
$ROA_{i,t}$	Firm i's earnings before interest and taxes in the year t divided by firm i's total assets in year t	Compustat
$Sales\ Growth_{i,t}$	The difference between firm i's total sales in year $t-1$ and that in year t divided by firm i's total sales in year $t-1$	Compustat
$Slacks_{i,t}$	Firm i's cash and short-term investments in the year t divided by firm i's total assets in year t	Compustat
$Leverage_{i,t}$	Firm i's total liabilities divided by firm i's total assets in year t	Compustat
$R\&D_{i,t}$	Firm i's R&D expenses in year t divided by firm i's total sales in year t in percentage	Compustat
Moderating variables		
$ShortRelation_{i,t}$	$ShortRelation_{i,t} = 1$ if the average duration of firm i's customer relationships is shorter than the sample median in year t and 0 otherwise. The relationship duration of a firm's customer is measured by the number of years from the initiation of the supplier-customer relationship and the latest year of contracting.	Compustat customer segment
$FrequentOrdering_{i,t}$	$FrequentOrdering_{i,t} = 1$ if the average customer ordering frequency of firm i is greater than the sample median in year t and 0 otherwise. The customer ordering frequency is the reciprocal of the average number of days between any two successive contracts established between a customer and the firm.	Compustat customer segment
$LowTurnover_{i,t}$	$LowTurnover_{i,t} = 1$ if the inventory turnover of firm i is lower than the sample median in year t and 0 otherwise. The inventory turnover of a firm is the COGS divided by its total inventories.	Compustat
$SlowDepreciation_{i,t}$	$SlowDepreciation_{i,t} = 1$ if firm i's SIC in year t is between 35 and 38 (including industrial goods such as industrial machinery, electronic equipment, and transportation equipment) and 0 otherwise.	Compustat

Appendix B. An Example of Collecting Service Data in the 10-K Filings

Figure B.1 presents an illustration of how we use bag-of-words techniques to identify Boeing's service offerings in Item 1 (Business) of the 10-K filing. The matching algorithm will categorize keywords and tell us that Boeing mentions the keywords for eight service types. We therefore set the number of services offered $ServiceNum_{i,t}$ for Boeing in 2017 to eight.

Figure B.1. (Color online) An Example of Collecting Service Data in Boeing's 10-K Filing



EDGAR | Company Search Results

FAQ EDGAR search tools Feedback Classic version

Home » Company Search

BOEING CO BA on NYSE

Investor Toolkit: On

Filings

10-K	Annual report [Section 13 and 15(d), not S-K Item 405] Filing	2019-02-08	2018-12-31
10-K	Annual report [Section 13 and 15(d), not S-K Item 405] Filing	2018-02-12	2017-12-31

Data source: CIK0000012927.json

BOEING

UNITED STATES
SECURITIES AND EXCHANGE COMMISSION
Washington, D.C. 20549
FORM 10-K

Item 1. Business

The Boeing Company, together with its subsidiaries (herein referred to as "Boeing," the "Company," "we," "us," "our"), is one of the world's major aerospace firms.

We are organized based on the products and services we offer. We operate in four reportable segments:

- Commercial Airplanes (BCA);
- Defense, Space & Security (BDS);
- Global Services (BGS);
- Boeing Capital (BCC).

Commercial Airplanes Segment

This segment develops, produces and markets commercial jet aircraft and provides fleet support services, principally to the commercial airline industry worldwide. We are a leading producer of commercial aircraft and offer a family of commercial jetliners designed to meet a broad spectrum of global passenger and cargo requirements of airlines. This family of commercial jet aircraft in production includes the 737 narrow-body model and the 747, 767, 777 and 787 wide-body models. Development continues on the 787-10 and certain 737 MAX derivatives and the 777X program.

Defense, Space & Security Segment

This segment is engaged in the research, development, production and modification of manned and unmanned military aircraft and weapons systems for global strike, including fighter aircraft and missile systems; vertical lift, including rotorcraft and tilt-rotor aircraft; mobility, surveillance and engagement, including battle management, airborne, anti-submarine, transport and tanker aircraft. In addition, this segment is engaged in the research, development, production and modification of the following products and related services: strategic defense and intelligence systems, including strategic missile and defense systems, command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR), cyber and information solutions, and intelligence systems; satellite systems, including government and commercial satellites and space exploration.

BDS' primary customer is the United States Department of Defense (U.S. DoD). Revenues from the U.S. DoD, including foreign military sales through the U.S. government, accounted for approximately 79% of its 2017 revenues. Other significant BDS customers include the National Aeronautics and Space Administration (NASA) and customers in international defense, civil and commercial satellite markets.

This segment's primary products include the following fixed-wing military aircraft: EA-18G Growler Airborne Electronic Attack, F/A-18E/F Super Hornet, F-15 Strike Eagle, P-8 programs, and KC-46A Tanker. This segment produces rotorcraft and rotary-wing programs, such as CH-47 Chinook, AH-64 Apache, and V-22 Osprey. In addition, this segment's products include space and missile systems including: government and commercial satellites, the International Space Station, missile defense and weapons programs, and Joint Direct Attack Munition, as well as the United Launch Alliance joint venture.

Global Services Segment

This segment provides services to our commercial and defense customers. This segment offers aviation services support, aircraft modifications, spare parts, training, maintenance documents, data analytics and information-based services, and technical advice to commercial and government customers worldwide.

In addition, BGS sustains aircraft and systems with a full spectrum of products and services through integrated logistics, including supply chain management and engineering support, maintenance, modification and upgrades for aircraft; and training systems and government services, including pilot and maintenance training. Major defense programs supported include the C-17 Globemaster III, F-15 Strike Eagle, F/A-18E/F Super Hornet, and AH-64 Apache for domestic and international customers.

Boeing Capital Segment

BCC seeks to ensure that Boeing customers have the financing they need to buy and take delivery of their Boeing product and manages overall financing exposure. BCC's portfolio consists of equipment under operating leases, finance leases, notes and other receivables, assets held for sale or re-lease and investments.

Firm Name	The Boeing Company	
Ticker	BA	
Exchange	New York Stock Exchange	
CIK	0000012927	
Fiscal Year	2017	
Service Offerings	- Logistic services; - Spare parts and technical support; - Maintenance and repair services; - Consultancy services;	- Integrated solutions; - Digital and streaming services; - Renewal and end-of-life services; - Leasing services.
ServiceNum	8	

Endnotes

[1] Text documents of the public firm's SEC filings are available at https://www.sec.gov/edgar/search/.

[2] Readers are directed to Online Appendix A for details on the data set used, time span, and variable fields.

[3] The SEC stipulates that "Item 1 "Business" requires a description of the company's business, including its main products and services, what subsidiaries it owns, and what markets it operates in" (https://www.investor.gov/introduction-investing/general-resources/news-alerts/alerts-bulletins/investor-bulletins/how-read, date accessed April 13, 2024).

[4] Form 10-K405 is a Form 10-K in which a box on the first page is checked, indicating that "disclosure of delinquent filers pursuant to Item 405" is not included in the current filing. The SEC abolished this distinction in 2003 because of confusion and inconsistent application. As this distinction does not affect our study, we incorporate both form types into the sample and collectively refer to them as 10-Ks.

[5] In Online Appendix B are the further details regarding the construction of manufacturers' service offerings.

[6] We use quarterly price deflators from the Bureau of Economic Analysis to adjust inventories and cost of goods sold.

[7] Readers may refer to Online Appendix B for key statistics of identified services, time trend of servitization, and representative servitized firms.

[8] Service sales are not chosen because of inconsistent business division names hindering cross-company service sales comparisons. Instead, 10-K reports' objective business terms, compelled by disclosure regulations, provide more reliable data. Moreover, recognizable service phrases in 10-Ks facilitate service classifications (e.g., complementing and substituting services), discussed in Section 5.3.

[9] SEC Regulation S-K requires all U.S. publicly traded companies to disclose their principal customers accounting for more than 10% of their total sales (Osadchiy et al. 2021).

[10] Firm-level fixed effects are not included because our data set comprises multiple years in which a firm does not experience variation in service quantities, and eliminating these observations would bias the results (Shah et al. 2017).

[11] Readers may refer to Online Appendix C for the association plots, model-free analyses, and findings on the gradual shifts in *DV* and *BWE* as service numbers increase.

[12] CEM is a technique used to identify matched samples by coarsening a set of covariates. CEM restricts each covariate to the common support range and handles missing values with multiple imputation methods to ensure that each stratum has at least one treatment and one control unit (Iacus et al. 2012). Strata in CEM that have no matching untreated pitches are pruned from the data, along with untreated pitches that have no matching treated pitch (Kim and King 2014). One significant difference between CEM and the widely used propensity score matching (PSM) technique is that PSM requires determining the size of the matched control group ex ante and then ensuring balance ex post, whereas CEM performs the balancing ex ante.

[13] Previous research identifies industry maturity, industry competition, industry R&D expenses, industry turbulence, and industry cyclicality as factors impacting servitization (Fang et al. 2008, Suarez et al. 2013, Cusumano et al. 2015).

[14] Readers may refer to Online Appendix D for the balance tests.

[15] Readers may refer to Online Appendix B for a graphical representation showing the average number of complementing versus substituting services over the years.

[16] Only a few companies initially provide substituting services (less than 5% of observations), so here we enforce the data in a way that firms with substituting services also have complementing services. We conduct robustness checks by removing observations of firms originally identified as providing substituting services first or those that switch between providing and not providing services over the entire sample period. The results are consistently align with the main findings.

[17] We propose a toy model forecasting same patterns that demand variability will first decrease, followed by a decrease in the intrafirm bullwhip as the firm shifts from complementing to substituting services. For details on the toy model, readers can refer to Online Appendix E.

[18] Readers can refer to the Online Appendix D for parallel trend tests and robustness checks using Bartik's instrumental variables, alternative samples, and placebo tests.

[19] Readers may refer to Online Appendix F for a literature review on state-of-the-art large language models–related business research and the details of the GPT experiment.

[20] Zero-shot prompts are input instructions without providing any examples. Chain-of-thought prompts guide GPT to break down the task into several small steps.

[21] Processing a sample from seven firms, covering a total token count via the GPT API, took about two hours—significantly longer than the bag-of-words method, which required only five minutes. Therefore, using GPT models for an entire data set can be expected to be resource intensive and time-consuming.

References

Agrawal VV, Bellos I (2017) The potential of servicizing as a green business model. *Management Sci.* 63(5):1545–1562.

Agrawal VV, Ferguson M, Toktay LB, Thomas VM (2012) Is leasing greener than selling? *Management Sci.* 58(3):523–533.

Baines T, Lightfoot H (2013) *Made to Serve: How Manufacturers Can Compete Through Servitization and Product-Service Systems* (Wiley and Sons, Inc., Chichester, UK).

Bakshi N, Kim SH, Savva N (2015) Signaling new product reliability with after-sales service contracts. *Management Sci.* 61(8):1812–1829.

Bedi G (2020) How "as-a-service" models can improve business outcomes. *Forbes* (May 1), https://www.forbes.com/sites/forbesbusinessdevelopmentcouncil/2020/05/01/how-as-a-service-models-can-improve-business-outcomes/?sh=346126e9480b.

Bray RL, Mendelson H (2012) Information transmission and the bullwhip effect: An empirical investigation. *Management Sci.* 58(5):860–875.

Büschken J, Allenby GM (2020) Improving text analysis using sentence conjunctions and punctuation. *Marketing Sci.* 39(4):727–742.

Cachon GP, Olivares M (2010) Drivers of finished-goods inventory in the US automobile industry. *Management Sci.* 56(1):202–216.

Cachon GP, Randall T, Schmidt GM (2007) In search of the bullwhip effect. *Manufacturing Service Oper. Management* 9(4):457–479.

Chen F, Drezner Z, Ryan JK, Simchi-Levi D (2000) Quantifying the bullwhip effect in a simple supply chain: The impact of forecasting, lead times, and information. *Management Sci.* 46(3):436–443.

Cohen MA, Agrawal N, Agrawal V (2006) Winning in the aftermarket. *Harvard Bus. Rev.* 84(5):129–138.

Croson R, Donohue K (2006) Behavioral causes of the bullwhip effect and the observed value of inventory information. *Management Sci.* 52(3):323–336.

Cusumano MA, Kahl SJ, Suarez FF (2015) Services, industry evolution, and the competitive strategies of product firms. *Strategic Management J.* 36(4):559–575.

David I, Zhou L, Qin K, Song D, Cavallaro L, Gervais A (2023) Do you still need a manual smart contract audit? Preprint, submitted June 21, https://arxiv.org/abs/2306.12338.

Deloitte (2020) Aftermarket services: Transforming manufacturing in the wake of the COVID-19 pandemic. Accessed April 13, 2024, https://www2.deloitte.com/content/dam/insights/us/articles/6494_aftermarket-services/DI_Rise-of-Aftermarket-services.pdf.

Fang E, Palmatier RW, Steenkamp JBEM (2008) Effect of service transition strategies on firm value. *J. Marketing* 72(5):1–14.

Gallino S, Moreno A, Stamatopoulos I (2017) Channel integration, sales dispersion, and inventory management. *Management Sci.* 63(9):2813–2831.

Gao Y, Duan W, Rui H (2022) Does social media accelerate product recalls? Evidence from the pharmaceutical industry. *Inform. Systems Res.* 33(3):954–977.

Girotra K, Netessine S (2013) OM forum—Business model innovation for sustainability. *Manufacturing Service Oper. Management* 15(4):537–544.

Guajardo JA, Cohen MA (2018) Service differentiation and operating segments: A framework and an application to after-sales services. *Manufacturing Service Oper. Management* 20(3):440–454.

Guajardo JA, Cohen MA, Netessine S (2016) Service competition and product quality in the US automobile industry. *Management Sci.* 62(7):1860–1877.

Hellenic Shipping News Worldwide (2022) Global trade slows and supply chains remain unbalanced. (August 11), https://www.hellenicshippingnews.com/global-trade-slows-and-supply-chains-remain-unbalanced/.

Iacus SM, King G, Porro G (2012) Causal inference without balance checking: Coarsened exact matching. *Political Anal.* 20(1):1–24.

Jain N, Hasija S, Popescu DG (2013) Optimal contracts for outsourcing of repair and restoration services. *Oper. Res.* 61(6):1295–1311.

Jegadeesh N, Wu D (2013) Word power: A new approach for content analysis. *J. Financial Econom.* 110(3):712–729.

Kastalli IV, Van Looy B (2013) Servitization: Disentangling the impact of service business model innovation on manufacturing firm performance. *J. Oper. Management* 31(4):169–180.

Kim JW, King BG (2014) Seeing stars: Matthew effects and status bias in Major League Baseball umpiring. *Management Sci.* 60(11):2619–2644.

Kim SH, Cohen MA, Netessine S (2007) Performance contracting in after-sales service supply chains. *Management Sci.* 53(12):1843–1858.

Lee HL, Padmanabhan V, Whang S (1997) Information distortion in a supply chain: The bullwhip effect. *Management Sci.* 43(4):546–558.

Liu X, Mishra A, Goldstein S, Sinha KK (2019) Toward improving factory working conditions in developing countries: An empirical analysis of Bangladesh ready-made garment factories. *Manufacturing Service Oper. Management* 21(2):379–397.

Loughran T, McDonald B (2016) Textual analysis in accounting and finance: A survey. *J. Accounting Res.* 54(4):1187–1230.

Lu LX, Lariviere MA (2012) Capacity allocation over a long horizon: The return on turn-and-earn. *Manufacturing Service Oper. Management* 14(1):24–41.

Moritz BB, Narayanan A, Parker C (2022) Unraveling behavioral ordering: Relative costs and the bullwhip effect. *Manufacturing Service Oper. Management* 24(3):1733–1750.

Muthulingam S, Corbett CJ, Benartzi S, Oppenheim B (2013) Energy efficiency in small and medium-sized manufacturing firms: Order effects and the adoption of process improvement recommendations. *Manufacturing Service Oper. Management* 15(4):596–615.

Olivares M, Cachon GP (2009) Competing retailers and inventory: An empirical investigation of general motors' dealerships in isolated us markets. *Management Sci.* 55(9):1586–1604.

Örsdemir A, Deshpande V, Parlaktürk AK (2019) Is servicization a win–win strategy? Profitability and environmental implications of servicization. *Manufacturing Service Oper. Management* 21(3):674–691.

Osadchiy N, Schmidt W, Wu J (2021) The bullwhip effect in supply networks. *Management Sci.* 67(10):6153–6173.

Ramdas K, Randall T (2008) Does component sharing help or hurt reliability? An empirical study in the automotive industry. *Management Sci.* 54(5):922–938.

Roels G, Karmarkar US, Carr S (2010) Contracting for collaborative services. *Management Sci.* 56(5):849–863.

Shah R, Ball GP, Netessine S (2017) Plant operations and product recalls in the automotive industry: An empirical investigation. *Management Sci.* 63(8):2439–2459.

Suarez FF, Cusumano MA, Kahl SJ (2013) Services and the business models of product firms: An empirical analysis of the software industry. *Management Sci.* 59(2):420–435.

Terwiesch C (2023) Let's cast a critical eye over business ideas from ChatGPT. *Financial Times* (March 13), https://www.ft.com/content/591ad272-6419-4f2c-9935-caff1d670f08.

Tunca TI, Zhu W (2018) Buyer intermediation in supplier finance. *Management Sci.* 64(12):5631–5650.

Zhao H, Xiong C, Gavirneni S, Fein A (2012) Fee-for-service contracts in pharmaceutical distribution supply chains: Design, analysis, and management. *Manufacturing Service Oper. Management* 14(4):685–699.