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Returns to Cloud Computing Investment: The Role of Environmental Uncertainty

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Despite the significant potential of cloud computing to help firms adapt to uncertain and turbulent environments through flexibility, scalability, and reconfigurability, empirical evidence remains limited. This study addresses this gap by examining the impact of cloud computing on productivity and how its effects vary across different levels of environmental uncertainty. Using a novel measure of purchased cloud services in U.S. industries from 1997 to 2018, we further distinguish between software-as-a-service (SaaS) and infrastructure-as-a-service (IaaS). Employing a production function approach, our findings suggest that cloud computing investments do not uniformly translate into productivity gains. Instead, we observe significant variation depending on environmental conditions: while cloud computing enhances productivity in industries facing high uncertainty, it can even have adverse effects in highly stable environments. Moreover, the positive productivity effects under uncertainty appear to be driven primarily by IaaS rather than SaaS. Our findings contribute to the literature and offer important implications for IT strategy and digital resilience.

Keyword: Cloud computing, Software-as-a-Service, Infrastructure-as-a-Service, IT outsourcing, IT productivity, Digital resilience

Ⅰ. Introduction

Information technology (IT) investments have been suggested as a main driver of productivity and organizational performance (Brynjolfsson and Hitt, 1996; Melville et al., 2004; Choi and Moon, 2015). Over the past decades, cloud computing—an IT service model in which computing resources and applications are delivered over the Internet—has been widely adopted across industries, driven by advantages such as elasticity, scalability, continuous availability, and pay-as-you-go pricing (Marston et al., 2011). According to the IT trend report by the Society for Information Management (2022), cloud computing emerged as the leading area of organizational investment in

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2021, following its return to the top in 2020 for the first time since 2010. This trend reflects the increasingly widespread adoption of cloud-based technologies in recent years. In parallel with its growing prominence, prior research has documented the positive contributions of cloud computing to firm performance, including productivity, organizational growth, and survival (Caldarola and Fontanelli, 2025; DeStefano et al., 2023; Jin and McElheran, 2024). Beyond economic outcomes, scholars have also emphasized its broader societal implications, such as its potential to advance environmental sustainability (Park et al., 2023a).

Cloud computing has become an imperative for firms pursuing digital transformation, especially since the COVID-19 pandemic, which underscored the critical role of IT in fostering organizational adaptation and resilience amid rapidly evolving business environments and crisis-induced stressors (Lee et al., 2022). However, the benefits of cloud computing observed under normal conditions do not necessarily extend to periods of uncertainty (Park et al., 2023b). Despite the rapid expansion of cloud computing across industries and growing evidence of its economic benefits, it remains unclear whether cloud adoption provides advantages under highly uncertain conditions, by enabling adaptation to environmental uncertainty, strengthening organizational resilience, and thereby sustaining productivity growth.

Moreover, different cloud service models carry distinct implications for business operations in how firms adapt to changing environments. Infrastructure-as-a-service (IaaS) provides on-demand access to computing resources such as storage, networking, and servers, enabling flexibility and scalability in response to environmental shifts. In contrast, software-as-a-service (SaaS) delivers software and applications over the Internet, allowing firms to reconfigure services and experiment with new applications to meet evolving demands. The lack of systematic investigation into how different cloud service models influence productivity constrains both theoretical insights and practical guidance available for firms formulating IT investment strategies. To fill this gap, this study addresses the following research questions:

RQ1. Do investments in cloud computing contribute to productivity?

RQ2. How does their effect on productivity vary with environmental uncertainty?

RQ3. Which types of cloud services are most instrumental in enhancing productivity under highly uncertain conditions?

The impact of cloud computing on productivity growth under varying levels of environmental uncertainty remains to be empirically established. Prior research suggests that IT has greater effects in uncertain and dynamically changing environments (Melville et al., 2007; Sabherwal et al., 2019), and this may be especially true for cloud computing given its flexibility, mobility, and scalability (DeStefano et al., 2023; Jin and McElheran, 2024). By allowing firms to scale resources and reconfigure processes in response to fluctuating demand and external shocks, cloud computing reduces the need for upfront infrastructure investments and enhances agility, market responsiveness, and business process redesign, which are particularly valuable under unstable and turbulent conditions (Battleson et al., 2016; Fazli et al., 2018). However, cloud adoption also carries risks, including implementation failures, limited customization, loss of control, and security concerns (CIO Magazine, 2019; Kathuria et al., 2018). In particular, organizational transformation such as cloud migration during turbulent times may further entail significant coordination costs, making cloud computing investments riskier (Park et al., 2023b). While prior studies highlight heterogeneous impacts of cloud computing across firm characteristics such as tenure and size, empirical evidence on its economic value and the moderating role of environmental uncertainty remains limited.

To empirically investigate the productivity impact of cloud computing and the moderating role of environmental uncertainty, we adopt the approach of Park et al. (2023a) to construct an industry-level measure of cloud computing based on cloud services purchased by U.S. industries between 1997 and 2018. Specifically, our analysis combines granular product sales data from the U.S. Economic Census with inter-industry purchase flows obtained from input - output tables. A key advantage of this measure is that it enables us to distinguish between two major types of cloud computing: SaaS and IaaS. Employing a production function framework, we separate cloud computing and non-cloud IT services from intermediate inputs to estimate their respective impacts on productivity, consistent with prior research (Han et al., 2011; Park et al., 2023a). In addition, environmental uncertainty is operationalized through measures of industry dynamism and concentration, consistent with prior studies (Chung et al., 2019; Melville et al., 2007).

Our findings reveal that the payoffs from cloud computing investments are far from universal; instead, their impact on productivity varies with the degree of environmental uncertainty. While cloud computing enhances productivity in industries operating under high uncertainty, it can even exert adverse effects in highly stable environments. Moreover, the productivity gains observed in uncertain environments are driven predominantly by IaaS rather than SaaS. Under such turbulent conditions, the marginal product of IaaS is estimated to be several orders of magnitude higher than that of internal IT capital and non-cloud IT outsourcing, underscoring its pivotal role in fostering organizational adaptability and resilience.

This study contributes to the information systems (IS) literature on the business value of IT by providing empirical evidence on the economic returns of cloud computing investments. To the best of our knowledge, it is the first to provide empirical evidence on the contingent effects of such investments under varying levels of environmental uncertainty. Our findings highlight how cloud computing enhances organizational resilience, enabling firms to adapt more effectively to turbulent and unpredictable environments. In particular, we distinguish between the roles of SaaS and IaaS, showing that IaaS plays a critical role in sustaining productivity gains during periods of uncertainty. This research deepens the theoretical understanding of IT value creation and delivers practical guidance for firms shaping cloud-era IT strategies to build resilience in uncertain environments.

Ⅱ. Related Literature

Over the past few decades, a substantial body of IS research has investigated the economic value of IT. This literature has converged on a broad consensus that IT investments are positively associated with productivity across multiple levels of analysis, including the firm, industry, and national economy (Brynjolfsson and Hitt, 1996; Dewan and Kraemer, 2000; Jorgenson and Stiroh, 2000; Melville et al., 2004; Stiroh, 2002; Tambe and Hitt, 2012).

As IT outsourcing—the use of a third-party vendor to provide IT services that were previously provided internally—has accounted for an increasingly large part of total IT investments, studies have documented the significant role of IT outsourcing in productivity gains (Agrawal et al., 2006; Han et al., 2011). Chang and Gurbaxani (2012) suggest that IT knowledge transmitted from vendors is a major driver of productivity gains from IT outsourcing. Thouin et al. (2009) argue that outsourcing network and telecommunication services that have become commodities (i.e., low-specificity assets) is positively related to the focal firm's financial performance. Han and Mithas (2013) further present empirical evidence that IT outsourcing can contribute to the reduction in non-IT costs by increasing the operational efficiencies of existing processes and allowing the reallocation of internal IT resources. More recently, Jin and McElheran (2024) investigate how IT strategy influences the performance of young U.S. manufacturing businesses, focusing on the tradeoffs between IT outsourcing and owned IT capital. Using Census microdata from

2006-2014, they show that younger establishments disproportionately benefit from outsourcing, which enhances flexibility and survival by reducing uncertainty.

As IT outsourcing undergoes a fundamental transformation driven by cloud services and their distinct value appropriation logics (Kathuria et al., 2018), prior studies have increasingly examined the business value of cloud computing. DeStefano et al. (2023) analyze UK firms and show that cloud adoption enables younger firms to expand revenue, employment, and productivity, while incumbents experience weaker gains and restructuring through establishment closures. It emphasizes that cloud computing reduces the fixed costs of IT, enables "scale without mass," and facilitates geographic reorganization, thereby reshaping competition and lowering barriers to growth for younger and smaller firms. Similarly, Caldarola and Fontanelli (2025) use French firm-level data to examine the impact of cloud adoption on long-run firm growth. They find that cloud use stimulates growth rates more strongly for smaller firms than for larger ones, particularly when firms adopt cloud-based software applications for administration and customer management. Their endogenous treatment model, which uses lightning strikes as an instrument for broadband reliability, confirms a causal relationship between cloud adoption and scaling potential. In addition, several studies and industry reports have attempted to assess the economic value of cloud computing at the macroeconomic level (Hooton, 2019; Wauters et al., 2016).

Notably, Jin and McElheran (2024) demonstrate that the first five years of a firm's existence are the most IT-productive, challenging the conventional view that scale advantages primarily drive IT returns. Their analysis further reveals that these dynamics are shaped more by environmental uncertainty than by firm size, as well as by the rise of cloud-based outsourcing after 2009, underscoring the significant role of cloud computing in navigating uncertain environments. While Kathuria et al. (2018) provide survey-based evidence from Indian firms that cloud computing improves business flexibility, responsiveness, and scalability, the question of whether such benefits translate into productivity gains under high environmental uncertainty remains unaddressed. Moreover, the literature has yet to fully disentangle the distinct contributions of different types of cloud services (e.g., SaaS versus IaaS) to firm outcomes.

Addressing these gaps, our study focuses explicitly on the differential impacts of SaaS and IaaS and investigates how environmental uncertainty conditions their economic value, thereby advancing both theory and practice in the business value of IT literature.

Ⅲ. Conceptual Framework

The literature has highlighted the role of competitive regimes and environmental uncertainty in shaping business operations, where environmental uncertainty refers to the extent to which future states of the competitive environment are difficult to anticipate or predict, thereby complicating decision-making (Dess and Beard, 1984). In particular, prior research has revealed that environmental uncertainty moderates IT's impacts on productivity (Melville et al., 2007), make-or-buy decision (Ray et al., 2009), supply chain-related operational performance (Wong et al., 2011), and value of software patents (Chung et al., 2019). Building on this research stream, we argue that the benefits of cloud computing are likewise contingent on environmental uncertainty, with the magnitude of its contribution varying across different service models (i.e., SaaS vs. IaaS).

First, cloud computing, IaaS in particular, enables firms to rapidly and flexibly scale IT resources up or down to meet uncertain and volatile demand, while avoiding the need for extensive upfront planning, large capital expenditures, lengthy implementation times, and long-term contracts. A unique feature of cloud computing is its ability to replace clients' fixed costs for internal IT infrastructure with usage-based variable costs for services delivered through the cloud (Armbrust et al., 2010). In addition, decoupling of IT resources through virtualization facilitates flexible and elastic scaling (Benlian et al., 2018), while scalable cloud services are capable of executing large batch-oriented tasks as quickly as programs can scale (Armbrust et al., 2010). This cloud-driven flexibility and agility promote the optimal utilization of IT resources, thereby minimizing the impact of unforeseen shocks and volatilities. Moreover, autoscaling in cloud computing provides automatic and optimal adjustment of computational capacity in both proactive and reactive ways in response to hazards (Fazli et al., 2018). For example, the global video-conferencing provider BlueJeans, which has supported employees working from home, healthcare providers shifting to telehealth, and educators adopting distance learning, experienced a 300% surge in traffic during the first two weeks of the COVID-19 pandemic. By shifting critical workloads to Amazon EC2, the company was able to manage this explosive growth and scale seamlessly, nearly doubling the number of regions served, which would have been impossible without cloud computing (AWS 2022). Such cloud-enabled IT flexibility could have a positive effect on process integration capability and thereby firm performance (Han et al., 2017).

Second, cloud-based software and applications (i.e., SaaS) enable business experimentation by facilitating the exploration and exploitation of alternative opportunities and the reconfiguration of internal processes and service offerings. By offering a wide range of application and configuration options tailored to specific needs, SaaS allows firms to adapt more effectively to market demands and external environmental shifts (Benitez et al., 2018; Benlian et al., 2018). Ewens et al. (2018) argue that the advent of cloud computing has dramatically reduced the cost of experimentation, particularly for early-stage businesses. A case in point is the use of cloud-hosted A/B testing platforms, such as Optimizely and AB Tasty, which support digital experimentation and enhance organizational learning (Koning et al., 2022). Through SaaS, firms can mix and match ready-to-use applications to experiment with new configurations of processes and business models in a cost-effective and timely manner. In addition, communities of cloud users can facilitate firms' search processes by providing alternative approaches to address novel situations and by identifying viable options. As Iyer and Henderson (2012) note, "cloud technology allows multiple users to share data and processes owned by a vendor. The vendors can choose to allow their partners to modify and enhance this shared asset, while allowing all users to enjoy the benefits of continuous improvement" (p. 53). Thus, cloud-enabled experimentation and search, particularly through SaaS, play a crucial role in organizational learning, which is essential for adaptation to new environments and changes (March, 1991).

Taken together, cloud computing fosters the development of dynamic capabilities and organizational agility through the flexibility and scalability afforded by IaaS and the reconfigurability and experimentation enabled by SaaS. Specifically, IaaS serves as a highly flexible and scalable digital infrastructure, leveraging virtualization and economies of scale to provide firms with the ability to rapidly adjust IT resources in response to volatile and unpredictable market conditions. This adaptability is particularly valuable in environments characterized by high uncertainty, where firms must frequently reallocate resources, manage fluctuating demand, and respond to sudden disruptions. By lowering adjustment costs and reducing the risks associated with over- or under-investment in IT capital, IaaS enables firms to preserve operational continuity while pursuing strategic opportunities in turbulent environments. In contrast, SaaS offers affordable, on-demand access to advanced software applications and supports process integration with significant potential for adaptation and experimentation. Together, these cloud service models strengthen firms' dynamic capabilities and enhance organizational resilience. Since business flexibility and responsiveness are critical for firms to navigate uncertain external environments (Sambamurthy et al., 2003), we expect that the productivity gains from cloud computing—especially from IaaS—will be greater under unstable and turbulent conditions.

Despite its widely recognized benefits, it is noteworthy that the flexibility and scalability of cloud computing may entail important trade-offs. For instance, hourly costs of cloud services can exceed amortized hourly costs of on-premises applications over their useful life. Consequently, in relatively stable environments with predictable computational workloads, hosting such workloads on the cloud may prove to be more expensive than maintaining them internally, thereby diminishing the productivity gains of cloud adoption. Moreover, cloud-based services and business models are not without risk, particularly given documented instances of cloud implementation failures (Kathuria et al., 2018). These risks may be amplified in uncertain and rapidly changing environments, where significant coordination costs are often imposed (Park et al., 2023b). In light of these concerns, an empirical investigation into the economic value of cloud computing is warranted, particularly with regard to the moderating role of environmental uncertainty.

Ⅳ. Data and Variables

4.1 Data Descriptions

For the empirical analysis, we draw on economy-wide panel data covering U.S. private industries from 1997 to 2018, sourced from the U.S. Bureau of Labor Statistics' Multifactor Productivity (MFP) database. This database reports annual measures of output, capital stock, labor costs, and intermediate input costs at the three-digit North American Industry Classification System (NAICS) level. We exclude one industry—water transportation (NAICS 483)—as it has employed no IT services; See Table A1 in the Appendix for the full list of 57 industries. Table 1 presents the variables used in our analysis, while Table A2 in the Appendix reports their correlations.

For capital inputs, we rely on data for productive capital stocks in 2012 constant dollars, which reflect the income-generating capacity of existing assets in a given period. Hardware (HW) capital is defined as the productive stock of "computers" and "communication equipment" within the information capital category, while software (SW) capital corresponds to the productive stock of "software" under the intellectual property capital category. We construct IT capital as the sum of HW and SW capital, and derive non-IT capital by subtracting IT capital from total capital. The

〈Table 1〉 Summary Statistics (N = 1,254 for 57 Industries during 1997-2018)

Variables	Mean	Std. Dev.	Min.	Max.	Descriptions
Output	361,499	347,923.3	13,493.64	1,636,212	Gross output by industry
IT capital	21,253.91	49,520.65	149	664,487	Productive capital stock of computers, communication equipment, and software by industry
Non-IT capital	543,716.8	907,079	22,096	6,227,807	Productive capital stock of total capital, excluding IT capital by industry
Labor	126,758.4	152,720.7	5,652.25	1,107,012	Labor cost by industry
Other intermediate inputs	169,286.9	178,065.9	3,603.38	873,681.1	Intermediate inputs, excluding cloud and non-cloud IT services by industry
Non-cloud IT services	3,319.63	4,778.56	35.43	34,195.09	Purchased IT services other than cloud computing
Cloud computing	395.70	789.44	0.21	8,776.25	Sum of SaaS and IaaS
SaaS	195.53	416.21	0	4,590.30	Purchased services of application provisioning (Software-as-a-Service), defined in Table 2
IaaS	200.17	378.24	0.18	4,185.95	Purchased services of IT infrastructure provisioning (Infrastructure-as-a-Service), defined in Table 2

Notes: All output and input variables are in millions of constant 2012 U.S. dollars. Data on cloud computing investment are based on the approach of Park et al. (2023a).

latter consists of non-IT equipment (e.g., industrial and transportation equipment), structures (including land), and intellectual property products other than software. Labor input is measured as total labor compensation within each industry.

4.2 Measurement of Cloud Computing

To empirically analyze the productivity effect of cloud computing investments and the moderating role of environmental uncertainty, we adopt the methodological framework of Park et al. (2023a). Their approach develops an industry-level measure of cloud computing investment using U.S. industry expenditures on cloud services. This measure reflects cross-industry variation in cloud computing investment, allowing us to examine its differential impact on productivity under varying levels of uncertainty. A further advantage is its basis in product-level data, which makes it possible to distinguish between the two major categories of cloud computing: SaaS and IaaS.

First, we identify product/service types for IT services outsourcing based on the North American Product Classification System (NAPCS). Data on industry sales by product/service type, as classified by NAPCS, are drawn from the U.S. Census Bureau's Economic Census. Consistent with prior studies (Han et al., 2011; Qu et al., 2011), we define an industry's IT outsourcing as the value of purchased services from two IT service sectors: Data Processing, Hosting, and Related Services (NAICS 5182) and Computer Systems Design and Related Services (NAICS 5415). Within these sectors, outsourced IT services are identified as product or service types that account for more than 1 percent of total sales. The list of IT service product types is reported in Table 2.

Second, we separate cloud-related IT services outsourcing from non-cloud IT outsourcing, acknowledging that cloud computing constitutes a subset of IT outsourcing (Choudhary and Vithayathil, 2013). Within the IT service categories listed in Table 2, we classify "application service provisioning" as SaaS, and IT infrastructure services such as website hosting, content streaming, and data storage as IaaS. While Platform-as-a-Service (PaaS) is another key element of cloud computing, it is not captured in our NAPCS-based measure, likely because it is dispersed across several IT service types (Park et al., 2023a).

Finally, we assess each industry's expenditure on cloud computing services used in production by utilizing inter-industry purchase

〈Table 2〉 Product Types of IT Services and Cloud Computing

Category		
Cloud Computing	Software-as-a-Service (SaaS)	Application service provisioning
	Infrastructure-as-a-Service (IaaS)	Website hosting services
		Video and audio streaming infrastructure provisioning services
		Data storage infrastructure provisioning services
		IT infrastructure collocation services
		Other IT infrastructure provisioning services
Non-Cloud IT Services	Business process management services	
	Data management services	
	Computer systems design, development, and integration services	
	Custom application design and development services	
	Network design and development services	
	IT infrastructure and network management services	
	Information and document transformation services	
	IT technical consulting services	
	IT technical support services	
	Temporary staffing - IT staff	

Notes: Product types are based on the North American Product Classification System (NAPCS).

flows. Following Han et al. (2011), who measure industry-level IT outsourcing using input–output use tables that record commodity outputs of one industry and the intermediate inputs purchased by another, we apply the same approach to cloud computing. Specifically, using the BLS input–output use tables, we calculate an industry's cloud service expenditure by summing its purchased intermediate inputs from industries, weighted by each supplying industry's share of sales attributable to cloud computing:

$$\text{Cloud}_{i,t} = \Sigma_j(\textit{sales percentage of cloud computing in industry } j \textit{ in year } t) \times (\textit{intermediate inputs from industry } j \textit{ to industry } i \textit{ in year } t)$$

As the Economic Census is conducted every five years, we interpolate the sales shares of cloud computing services for 1997-2018 linearly, based on the 2002, 2007, and 2012 data.

4.3 Measurement of Environmental Uncertainty

Environmental uncertainty has typically been defined by two factors: industry dynamism and industry concentration, with concentration serving as an inverse measure of competitiveness (Chung et al., 2019; Melville et al., 2007; Ray et al., 2009). Following this approach, we measure industry dynamism as the volatility of industry sales or output (Chung et al., 2019; Melville et al., 2007). Specifically, we regress the logarithm of industry output on a linear time trend over the preceding five years using rolling windows, and then take the antilog of the standard error of the estimated slope. To reduce distortions from temporary shocks such as the 2007–2008 financial crisis, we average these rolling measures over the 1997-2018 period. Table A1 reports the average level of environmental uncertainty across industries. To illustrate, the most uncertain industries include support services for mining and manufacturing, particularly those producing apparel, primary metals, machinery, and computer and electronic products, which are widely recognized as highly susceptible to economic cycles. By contrast, industries that produce essential goods, such as food and beverages and petroleum and coal products, as well as service industries such as restaurants, bars, hospitals, and health care services, appear most stable in terms of sales volatility over the years.

In addition, we employ two alternative measures of environmental uncertainty: (i) the coefficient of variation of output, and (ii) the inverse of the four-firm concentration ratio (CR4), computed as one minus CR4, using data obtained from the Economic Census. The results remain largely consistent across these alternative measures.

Ⅴ. Empirical Model

Conventional Cobb–Douglas production functions generally treat capital and labor as the main inputs to production. More recent research expands the framework by adding intermediate inputs purchased from other industries as a production input, where IT outsourcing is often considered part of this category (Han et al., 2011). Consistent with this literature, we employ an extended Cobb–Douglas production function that incorporates intermediate inputs and further distinguishes cloud computing and non-cloud IT services from other intermediate inputs, as follows:

$$Y = \alpha IT^{\beta_1} K^{\beta_2} L^{\beta_3} M^{\beta_4} O^{\beta_5} CC^{\beta_6},$$

where α is a technological change parameter capturing total factor productivity, and *Y*, *IT*, *K*, *L*, *M*, *O*, and *CC* denote output, IT capital, non-IT capital, labor, other intermediate inputs, non-cloud IT services, and cloud computing, respectively.

By applying logarithmic transformation to the Cobb–Douglas production function, we obtain the following log-linear specification:

$$\begin{aligned} ln(Y_{it}) = \alpha_i + \beta_1 lnIT_{it} + \beta_2 lnK_{it} + \beta_3 lnL_{it} \\ + \beta_4 M_{it} + \beta_5 O_{it} + \beta_6 lnCC_{it} + \tau_t + \varepsilon_{it}, \end{aligned}$$

where a random error for industry i in year t (ε_{it}) is considered. Since our dataset covers the entire private sector, we include industry fixed effects (α_i) to account for unobserved, time-invariant heterogeneity across industries (e.g., technological conditions, regulatory environments, production processes). Year fixed effects (τ_t) are also incorporated to control for shocks common to all industries, such as financial crises or nationwide shifts in cloud adoption. In the model specification, the estimated coefficients represent the output elasticities of the respective inputs, that is, the percentage change in output associated with a one-percent increase in each input. Among these, our primary parameter of interest is β_6, which measures the output elasticity of cloud computing and thereby captures its marginal contribution to productivity after accounting for the effects of other inputs, including in-house IT capital and non-cloud IT services. To examine the moderating role of environmental uncertainty, we further introduce an interaction term between environmental uncertainty and $lnCC_{it}$. For interpretability, all variables used in interaction terms are mean-centered.

Since our dataset combines both cross-sectional and time-series dimensions, we estimate the empirical model using panel feasible generalized least squares (FGLS) as well as regressions with panel-corrected standard errors (PCSE). These approaches adjust for industry-level heteroscedasticity, contemporaneous cross-panel correlations, and panel-specific first-order autocorrelation (PSAR1), in line with prior studies (Han et al., 2011; Ren and Dewan, 2015).

Ⅵ. Results

To assess whether cloud computing has contributed to productivity in U.S. industries, we estimate an empirical model using a pooled sample of 1,254 observations, covering 57 industries over 22 years. In Table 3, Column 1 reports the estimation results from the extended production function, in which both cloud-based and non-cloud IT services are treated as intermediate inputs. The estimated output elasticity of IT capital (0.23) falls within the range reported in prior studies; for instance, Stiroh (2005) notes a median estimate of 0.046 in the literature. The elasticity of non-cloud IT services outsourcing, which represents about 89% of total IT services outsourcing, is estimated at 0.12, closely matching Han et al. (2011), who report 0.21 using FGLS estimation. Compared with the significant positive contributions of in-house IT capital and non-cloud IT services to productivity, our results show that cloud computing (both SaaS and IaaS) is not significantly associated with productivity gains across U.S. industries. Nevertheless, this overall insignificant effect does not necessarily imply the absence of an impact; rather, it points to potential heterogeneity in cloud computing's contribution under specific conditions.

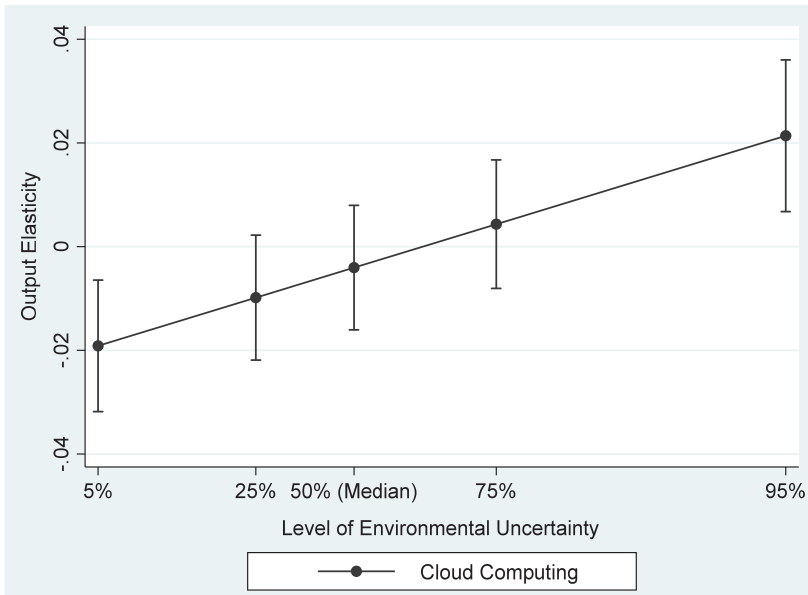
To explore heterogeneity in cloud computing's impact on productivity, we estimate the production function with an interaction term between cloud computing and environmental uncertainty. The results indicate that environmental uncertainty positively and significantly moderates cloud computing's contribution to productivity (Column 3), with the effect primarily driven by IaaS rather than SaaS (Column 4). Columns 5 and 6 confirm the robustness of these results using alternative measures of environmental uncertainty.

Figure 1 illustrates the relationship between output elasticity of cloud computing (i.e., the percentage change in output relative to the percentage change in cloud computing investment) and environmental uncertainty. The figure illustrates that cloud computing enhances productivity in industries operating under high environmental uncertainty, but may even exert adverse effects in highly stable environments (e.g., at the 5th percentile of environmental uncertainty). Figure 2 further distinguishes between SaaS and IaaS, revealing that SaaS has no significant effect across all levels of environmental uncertainty, while IaaS exhibits positive and significant effects under medium and high uncertainty. However, IaaS appears to have no significant

〈Table 3〉 Results of Production Function Estimations

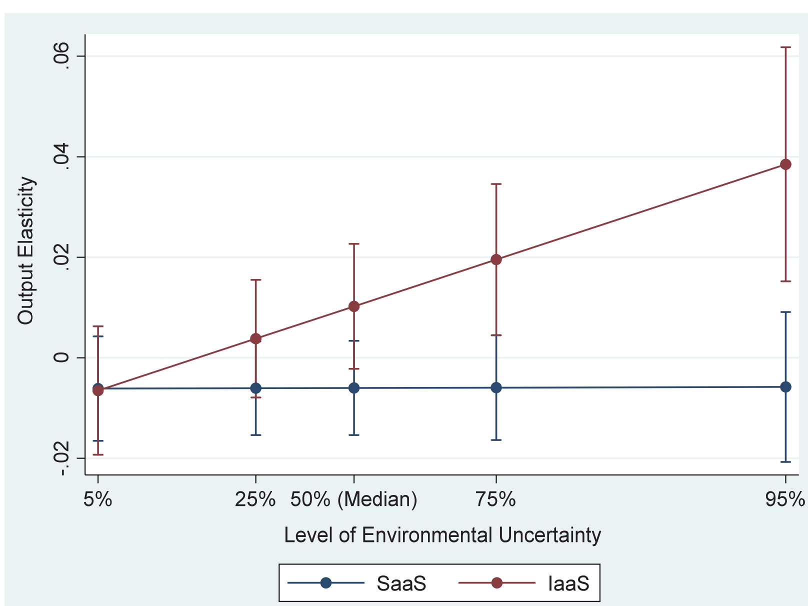
Dependent variable: Gross output	Panel FGLS					
	Measure of Environmental Uncertainty					
	Standard error of the slope of output regression on time				Coefficient of variation	Inverse of CR4
	(1)	(2)	(3)	(4)	(5)	(6)
IT capital	0.023*** (0.007)	0.025*** (0.007)	0.034*** (0.010)	0.038*** (0.010)	0.016* (0.009)	0.044*** (0.010)
Non-IT capital	0.241*** (0.018)	0.246*** (0.028)	0.257*** (0.022)	0.237*** (0.023)	0.233*** (0.024)	0.302*** (0.030)
Labor	0.469*** (0.018)	0.466*** (0.021)	0.450*** (0.016)	0.452*** (0.016)	0.412*** (0.020)	0.457*** (0.024)
Other intermediate inputs	0.213*** (0.007)	0.215*** (0.010)	0.212*** (0.008)	0.214*** (0.008)	0.173*** (0.009)	0.210*** (0.011)
Non-cloud IT services	0.012** (0.005)	0.004 (0.006)	0.012** (0.006)	0.006 (0.005)	0.008 (0.005)	-0.011** (0.006)
Cloud computing	-0.000 (0.005)		0.000 (0.006)			
SaaS		-0.001 (0.006)		-0.006 (0.005)	0.003 (0.004)	0.008** (0.003)
IaaS		0.011 (0.010)		0.015** (0.007)	0.013** (0.006)	0.020*** (0.007)
Uncertainty						-0.671*** (0.107)
Cloud computing × Uncertainty			2.919*** (0.460)			
SaaS × Uncertainty				0.024 (0.603)	0.015 (0.029)	-0.104*** (0.014)
IaaS × Uncertainty				3.242*** (0.931)	0.400*** (0.041)	0.170*** (0.032)
Industry Fixed-Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed-Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,254	1,254	1,254	1,254	1,254	1,100

Notes: Standard errors corrected for heteroscedasticity, panel-specific autocorrelation, and cross-sectional correlation, are in parentheses. All output and input variables are log-transformed. The main term of uncertainty is omitted for the first two measures of environmental uncertainty because they are measured at industry level.
* p 〈 0.1, ** p 〈 0.05, *** p 〈 0.01.



Notes: 95% confidence intervals are presented.

〈Figure 1〉 Output Elasticity of Cloud Computing by Environmental Uncertainty



Notes: 95% confidence intervals are presented.

〈Figure 2〉 Output Elasticities of IaaS Versus SaaS impact in relatively stable, low-uncertainty environments.

To evaluate the economic significance of cloud computing for productivity, we calculate the gross marginal products of production factors, defined as the additional output generated by a one-unit increase in a given input. Table 4 presents the estimated marginal products for IT capital, non-cloud IT services outsourcing, and cloud computing services.[1)] The results highlight a clear distinction: under high levels of environmental uncertainty, the marginal product of cloud computing is not only positive but also substantially higher than that of non-cloud IT services outsourcing and internal IT capital. By contrast, under low levels of environmental uncertainty, cloud computing may even undermine productivity. These dynamics are primarily driven by IaaS rather than SaaS. This finding underscores that IaaS provides superior returns in uncertain environments, where its flexibility and scalability allow firms to adapt more efficiently than with traditional IT investments. However, in more stable environments, relying on IaaS to source IT resources may increase operating costs relative to using internal IT capital. Taken together, these results reinforce the idea that the economic value of cloud computing—particularly IaaS—emerges most clearly when industries operate under conditions of heightened uncertainty.

It is noteworthy that our results show that SaaS has an insignificant effect on productivity, regardless of environmental uncertainty. Unlike IaaS, which provides more tangible benefits by offering flexible and scalable IT resources and infrastructure, SaaS delivers sophisticated IT applications such as AI that may not yet have been ready to generate productivity gains during the sample period, which extends up to 2018. New technologies often fail to produce immediate impacts without complementary investments such as business process redesigns and human resource management practices. This so-called productivity paradox has been observed since the early IT era (Brynjolfsson 1993) and has been extended to contemporary technologies such as AI, shaping what is known as the productivity J-curve (Brynjolfsson et al., 2021). Although SaaS enables firms to access advanced software and applications such as AI models on demand via the Internet (Park et al., 2023a), many firms may not yet have had the complementary business models and processes necessary to realize productivity benefits, given that our sample period covers the relatively

1) Note that the marginal products of IT capital and non-cloud IT services under different levels of environmental uncertainty cannot be computed, as our model does not incorporate interactions between these variables and environmental uncertainty. In Table 4, the marginal products of other production factors, including IT capital and non-cloud IT services, are reported to provide a benchmark for assessing the economic significance of productivity gains from cloud computing.

〈Table 4〉 Marginal Products of Cloud Computing by Environmental Uncertainty

Production Factors	Gross Marginal Product				
IT capital	0.39				
Non-IT capital	0.16				
Labor	1.34				
Other intermediate inputs	0.45				
Non-cloud IT services	1.26				
Cloud computing	-0.37				
	Percentile of Level of Environmental Uncertainty				
	5%	25%	50%	75%	95%
Cloud computing	-17.48	-8.98	-3.70	3.96	19.55
Software-as-a-Service (SaaS)	-11.31	-11.17	-11.09	-10.96	-10.71
Infrastructure-as-a-Service (IaaS)	-11.76	6.89	18.49	35.31	69.53

Notes: Marginal products in the upper panel are calculated using Column 1 of Table 3. In the lower panel, marginal products for cloud computing, as well as for SaaS and IaaS, across different percentiles of environmental uncertainty are computed based on Columns 3 and 4 of Table 3.

early stages of cloud computing and AI. According to the productivity J-curve hypothesis, we expect that SaaS will yield stronger productivity benefits in subsequent years, particularly as firms have accelerated digital transformation and cloud migration since the COVID-19 pandemic in 2020. Future research could extend our analysis to cover this more recent period.

Ⅶ. Discussion and Conclusion

As cloud computing continues to evolve and take a central role in firms' IT investment strategies, understanding its broader implications has become increasingly critical. Beyond cost savings and operational efficiency, cloud technologies are now viewed as enablers of agility and innovation, reshaping how firms respond to competitive pressures and external shocks. This study therefore goes beyond assessing the economic value of cloud computing in terms of productivity gains; it also highlights its potential to foster digital resilience, equipping firms with the flexibility and scalability provided by digital technologies to navigate uncertain and turbulent environments. By examining not only whether cloud computing drives productivity, but also under what conditions its value is amplified, we provide fresh insights into the strategic role of cloud investments in the digital era.

Our results reveal that cloud computing—particularly IaaS—serves as a powerful driver of productivity growth in industries operating under high environmental uncertainty, yet it may even exert adverse effects in highly stable environments. In uncertain and dynamic contexts, the marginal products of IaaS are estimated to be several times larger than those of internal IT capital and non-cloud IT services outsourcing, underscoring its strategic advantage when adaptability and rapid scaling are essential. By contrast, in stable and predictable settings, the contribution of IaaS becomes statistically insignificant and converges toward the modest returns of traditional IT investments, suggesting that the very flexibility that makes cloud computing valuable in volatile conditions offers little advantage, and may even generate negative consequences, when uncertainty is minimal. Taken together, these findings underscore the critical moderating role of environmental uncertainty in shaping the relative benefits of cloud computing, reinforcing the perspective that its value emerges most clearly when firms face conditions demanding agility, resilience, and scalable technological capacity.

This study contributes to the literature on the business value of IT, which has received sustained attention from prior IS research (Brynjolfsson and Hitt, 1996; Han et al., 2011), by being among the first to empirically assess the economic value of cloud computing investment. While a few recent studies have explored the effects of cloud computing on firm performance (e.g., Jin and McElheran, 2024), to the best of our knowledge, our research provides the first empirical evidence of the contingent value of cloud computing, showing that its impact depends critically on the level of environmental uncertainty. Furthermore, by adopting a novel industry-level measure of cloud service purchases (Park et al., 2023a), we disentangle the distinct effects of SaaS and IaaS across varying environmental conditions, thereby offering new insights into the differentiated roles of these cloud service models in driving productivity gains under unstable and uncertain environments.

Within the IS literature, IT capabilities have long been recognized as critical enablers of dynamic capabilities and organizational agility, equipping firms to rapidly integrate and reconfigure internal and external resources in response to shifts in the external environment (Overby et al., 2006; Sambamurthy et al., 2003). Building on this perspective, scholars have emphasized the pivotal role of IT and IS in sustaining organizational performance under conditions of uncertainty and turbulence (Melville et al., 2007; Sabherwal et al., 2019). Extending this research stream, the present study provides one of the first systematic empirical examinations of the potential of cloud computing to enhance organizational agility and resilience. In particular, cloud computing enables firms to flexibly scale services, redesign business processes, and reconfigure resource allocations, thereby supporting rapid and adaptive responses to uncertain and constantly evolving environments. In doing so, this study positions cloud computing as a strategic IT capability that not only enhances productivity and efficiency but also strengthens resilience, underscoring its value as a source of competitive advantage in volatile contexts.

For business managers, the benefits and drawbacks of migrating to the cloud must be carefully weighed against one another. Our findings suggest that investments in IaaS are particularly advantageous in business environments characterized by constant change and uncertainty, where flexibility and scalability are paramount. By contrast, in relatively stable environments, such investments may not only fail to generate productivity gains but could even have adverse effects. While pay-as-you-go cloud services can reduce upfront hardware costs and offer greater flexibility, they may ultimately prove more expensive than on-premises applications for certain computational workloads, particularly when computing demands are relatively stable and predictable. Thus, managers should approach cloud adoption as a contingent strategy, aligning investment decisions with the volatility and demands of their specific industry context.

It is important to note that cost savings and productivity growth are not the only dimensions to consider when evaluating cloud computing. In some cases, higher operating costs may be justified if cloud adoption enables the achievement of broader business objectives. For example, incumbent firms transitioning to the cloud often undergo organizational restructuring, decentralizing activities and granting greater local authority, even when immediate productivity effects are not evident. Likewise, for firms whose growth depends on scaling operations rapidly, cloud investments can be strategically justified as a long-term enabler of global expansion, despite higher short-term costs or reduced productivity. These observations suggest that the value of cloud computing extends beyond productivity gains and cost savings to encompass strategic flexibility, organizational transformation, and enhanced market responsiveness. In this regard, exploring these alternative dimensions of value creation and capture through cloud computing represents a promising direction for future research.

Moreover, relationships with vendors play an important role in realizing the value of cloud computing (Kim and Park 2018). In addition, firms of different sizes may possess varying levels of digital capabilities to effectively harness cloud computing (Yue and Choi 2025). Future research could examine the moderating factors that influence how firms reap productivity gains from cloud computing.

In addition, given our focus on productivity growth, environmental uncertainty is measured based on the volatility of industry outputs. However, firms may also face other forms of uncertainty, such as technological disruptions and regulatory risks. Extending our analysis to incorporate these alternative types of uncertainty would further advance our understanding of the role of cloud computing in helping firms navigate uncertain business environments.

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〈Appendix〉

〈Table A1〉 U.S. Private Industries

2007 NAICS Code	Industry	Average Environmental Uncertainty
11	**Agriculture, Forestry, Fishing and Hunting**	
113, 114, 115	Forestry, fishing, and related activities	-0.227
21	**Mining, Quarrying, and Oil and Gas Extraction**	
211	Oil and gas extraction	0.115
212	Mining, except oil and gas	0.066
213	Support activities for mining	6.530
22	**Utilities**	-0.634
23	**Construction**	-0.155
31-33	**Manufacturing**	
311, 312	Food, beverage, and tobacco products	-0.881
313, 314	Textile mills and textile product mills	0.325
315, 316	Apparel and leather and allied products	0.966
321	Wood products	0.375
322	Paper products	-0.495
323	Printing and related support activities	-0.216
324	Petroleum and coal products	-0.887
325	Chemical products	-0.111
326	Plastics and rubber products	-0.018
327	Nonmetallic mineral products	0.189
331	Primary metals	0.904
332	Fabricated metal products	0.524
333	Machinery	1.122
334	Computer and electronic products	0.770
335	Electrical equipment, appliances, and components	0.331
336	Transportation equipment	0.760
337	Furniture and related products	0.537
339	Miscellaneous manufacturing	-0.367
42	**Wholesale Trade**	0.125
44-45	**Retail Trade**	-0.422
48-49	**Transportation and Warehousing**	
481	Air transportation	-0.123
482	Railroad transportation	0.216
484	Truck transportation	0.028
485	Transit and ground passenger transportation	0.027
486	Pipeline transportation	0.149
487, 488, 492	Other transportation and support activities	-0.439
493	Warehousing and storage	-0.361
51	**Information**	
511	Publishing industries (including software)	-0.323
512	Motion picture and sound recording industries	-0.457
515, 517	Broadcasting and telecommunications	-0.482
518, 519	Information and data processing services	-0.173

〈Table A1〉 U.S. Private Industries (continue)

2007 NAICS Code	Industry	Average Environmental Uncertainty
52	**Finance and Insurance**	
521, 522	Federal Reserve banks, credit intermediation, and related activities	-0.449
523, 525	Securities, commodity contracts, fund, trusts and other financial investments and vehicles and related activities	0.697
524	Insurance carriers and related activities	0.197
53	**Real Estate and Rental and Leasing**	
531	Real estate	-0.370
532, 533	Rental and leasing services and lessors of intangible assets	0.019
54	**Professional, Scientific and Technical Services**	
5411	Legal services	-0.702
5415	Computer systems design and related services	0.035
541 ex. 5411, 5415	Miscellaneous professional, scientific, and technical services	-0.628
55	**Management of Companies and Enterprises**	-0.359
56	**Administrative and Support and Waste Management and Remediation Services**	
561	Administrative and support services	-0.196
562	Waste management and remediation services	-0.193
61	**Educational Services**	-0.317
62	**Health Care and Social Assistance**	
621	Ambulatory health care services	-0.935
622-623	Hospitals and nursing and residential care facilities	-0.848
624	Social assistance	-0.486
71	**Arts, Entertainment, and Recreation**	
711, 712	Performing arts, spectator sports, museums, and related activities	-0.576
713	Amusements, gambling, and recreation industries	-0.459
72	**Accommodation and Food Services**	
721	Accommodation	-0.270
722	Food services and drinking places	-0.776
81	**Other Services, except Government**	-0.669

Notes: For ease of interpretation, we standardized the measure of environmental uncertainty across industries to have a mean of zero and a standard deviation of one.

〈Table A2〉 Correlation Matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Output	1.00								
(2) IT capital	0.33	1.00							
(3) Non-IT capital	0.54	0.18	1.00						
(4) Labor	0.81	0.31	0.21	1.00					
(5) Other intermediate inputs	0.91	0.18	0.51	0.58	1.00				
(6) Non-cloud IT services	0.60	0.57	0.28	0.66	0.40	1.00			
(7) Cloud computing	0.51	0.57	0.18	0.56	0.34	0.72	1.00		
(8) SaaS	0.50	0.53	0.17	0.54	0.34	0.69	0.99	1.00	
(9) IaaS	0.51	0.61	0.18	0.56	0.33	0.74	0.99	0.97	1.00