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An Empirical Analysis of How the Digital Economy Drives Industrial Structure Upgrading

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Abstract: Digital technology has become pervasive in daily life, profoundly reshaping lifestyles and emerging as a pivotal force in transforming production modes and industrial structures. This paper employs a panel data model to examine the role of the digital economy in facilitating industrial structure upgrading, analysing its regional heterogeneity. The research indicates pronounced regional disparities in the impact of the digital economy on facilitating industrial structural upgrading. The effect is markedly significant in eastern regions, whereas it is statistically insignificant in central and western regions. Further analysis reveals that regional economic development level acts as a critical threshold variable—a conclusion that withstands a series of robustness tests, including endogeneity mitigation via 2SLS estimation, alternative variable measures, and outlier treatment. Based on these empirical findings, this paper proposes corresponding recommendations concerning digital infrastructure development, locally tailored digital economy strategies, and the integration of digital and traditional industries.

Keywords: Industrial Structure Upgrading; Digital Economy; Fixed Effects Model

1. Introduction

With the rapid development of digital technologies like the internet, blockchain, 5G, and artificial intelligence, the digital economy has emerged as the most dynamic driver of global economic growth, quietly ushering in the digital era. China's digital economy is poised to enter a new phase characterized by deepening application, regulated growth, and inclusive sharing. The digital economy, emerging from the integration of digital technologies and traditional industries, has evolved into a critical pillar of China's economic development.

Concurrently, China's primary sector retains a relatively high proportion, while the tertiary sector's share remains modest. The industrial structure is at a crucial juncture of transformation and upgrading, embarking on a pivotal transformation, with economic structures transitioning between old and new growth drivers, facing significant pressure for industrial restructuring. As the digital economy accelerates, the labour substitution it induces across industries will further catalyse industrial upgrading. Against this backdrop, investigating the interplay between the digital economy and industrial upgrading will contribute to sustaining stable economic growth, advancing the establishment of a modern industrial system, and fostering high-quality economic development in China.

Building upon theoretical analysis of the digital economy's impact on industrial upgrading, this paper employs fixed-effects models using panel data from 30 Chinese provinces (Tibet excluded due to incomplete data) spanning 2011–2020 for empirical testing. Threshold variables are incorporated into the analysis, alongside an examination of regional heterogeneity within the data.

2. Literature Review

Currently, numerous scholars focus on theoretical research into the connotations and characteristics of the digital economy. He [1] posits that the digital economy is a product underpinned by big data analytics, internet platforms, and artificial intelligence operational methods. Du [2] posits that the digital economy encompasses both digital industrialisation and industrial digitalisation. Digital industrialisation refers to the creation of new products or industries through the application of digital technologies, while industrial digitalisation involves integrating digital technologies with traditional industries to enhance production efficiency. Li [3] proposes, from a digital technology perspective, that the digital economy constitutes an economic form employing digital technologies for production. Based on Tencent Research Institute's "China 'Internet Plus' Digital Economy Index", multiple scholars have measured China's digital economic development across different years using methods such as entropy analysis, grey relational analysis, and kernel density estimation. Lin and Chen [4] contend that digital economic development is influenced by technological, economic, and social factors. Jiao and Sun [5] construct a digital economy evaluation framework comprising 23 tertiary indicators.

Regarding industrial structure upgrading, Li et al. [6] contend that industrial structure upgrading denotes a process where the industrial structure shifts towards the tertiary sector, characterised by the continuous increase in the tertiary sector's proportion and its rising status within the economy. Simultaneously, it represents enterprises' progression towards higher-level industries through technological innovation. Gan et al. [7], however, define industrial structure upgrading as the process whereby all three sectors and their respective internal components continuously enhance their own efficiency, thereby achieving ever-higher resource utilisation rates. Gou [8] contends that gauging the pace of industrial structure transformation and upgrading aids in measuring the effectiveness of industrial restructuring policies.

Regarding the effect how digital economy contribute to industrial structure upgrading, scholars have reached a relatively consistent conclusion from diverse perspectives: "the development of the digital economy can significantly promote industrial structure upgrading." Jing and Sun [9] suggests that digital economy development drives industrial structure upgrading, which in turn ultimately promotes high-quality economic growth. Qin et al. [10], however, identified an inverted U-shaped relationship between the digital economy and industrial structure upgrading, noting that China currently occupies a phase of markedly accelerated industrial upgrading. Tao and Zhou [11] quantified the impact of information industry-manufacturing integration on industrial upgrading, revealing a strong linkage between these sectors that accelerates structural transformation; Liu [12] contends that digital technologies drive the transition from traditional production methods to intelligent manufacturing, foster cross-sectoral integration, and increase the tertiary sector's share; Chen and Chen[13] employing new economic theory and static/dynamic spatial panel models, conclude that the digital economy facilitates industrial upgrading both within and across provincial regions; Hu et al. [14] utilise spatial Durbin models to establish that the coordinated development of digital economy industrial structure and employment structure positively promotes industrial upgrading, further revealing this effect possesses significant positive spatial spillover utility.

3. Theoretical

Presently, China's industrial restructuring proceeds at a sluggish pace, with uneven development levels between eastern and western regions. Amid intensifying international competition, China's relatively low capacity for independent innovation places it in a highly passive position. Firstly, integrating digital technologies with traditional industries facilitates the flow of production factors and propels transformations in production methods, thereby achieving industrial upgrading. Secondly, the proliferation of next-generation technologies like big data, cloud computing, and 5G is poised to spur the emergence of a multitude of new industries, thereby driving industrial advancement.

Digital technology has quietly permeated every sector of industry. The widespread adoption of e-commerce and the sharing economy has driven continuous improvements in agricultural production, management, distribution, and sales processes. This has significantly reduced production and marketing costs, enhanced resource utilisation efficiency, and facilitated the modernisation of agriculture – effectively upgrading the primary sector. For instance, digital applications enable precise agricultural operations, livestock feeding, and the regulation of temperature and humidity. The widespread adoption of platforms like Meituan and Ele.me has introduced novel sales models to the catering industry, substantially boosting merchant profits while saving customers time, enabling them to enjoy fine dining without leaving home. Within the secondary sector, industrial digital transformation has become the norm. The digital economy provides valuable insights across industrial procurement, R&D, production, logistics, and sales, while offering robust technological support for enhancing manufacturing standards, making enterprise development more efficient and intelligent. The extensive application of digital technology within the secondary sector is also evident in labour substitution, substantially reducing personnel costs. Many factories now operate fully automated machinery, creating safer and more efficient production environments. Concurrently, digital applications expand industrial enterprises' production scale, allowing human resources to be redeployed to more suitable roles. Within the tertiary sector, digital technology has spawned numerous emerging industries with vast development prospects. These new sectors absorb labour while enabling rapid economic operation and continuously increasing output value, representing an essential path for China's economic advancement.

Ultimately, whether through the integrated development of digital technology with traditional primary, secondary, and tertiary industries, or the creation of new sectors, data has been indispensable. Amidst intensifying global market competition, advancing both the digital industrialisation and industrial digitalisation of China represents a crucial measure for achieving high-quality economic development within the context of a once-in-a-century transformation. During industrial digitalisation, the digital economy enables enterprises to collect data through information platforms, fostering innovation to enhance production efficiency and coordination. Conversely, the digital economy reduces distribution costs, accelerates circulation speeds, and extends industrial chains. By elevating data, technology, and knowledge as primary drivers of productivity, the digital economy will undoubtedly usher in a new chapter of development for China.

4. Research Design

4.1 Econometric Model

To examine the impact of the digital economy on industrial structure upgrading, this study employs F-tests, Hausman tests, and LM tests, ultimately selecting a panel fixed-effects model.

$$isu_{it}=a+\beta \mathrm{dig}_{it}+\lambda_m \sum X_{it}+\mathrm{A_i}+\mathrm{B_t}+\mu_{it} \quad (1)$$

Where isu_{it} denotes the industrial structure upgrading level of province i in period t, and dig_{it} represents the digital economy level of province i in period t. A is the constant term, μ_{it} is the random error term, β is the coefficient for the digital economy effect, vector X is the control variable, and λ_m is the coefficient for the control variable effect. A represents the individual fixed effect, controlling for factors at the provincial level that do not change over time; B represents the time fixed effect.

Considering that industrial structure upgrading is affect by the digital economy and factors such as the degree of openness to the outside world, the degree of financial development , the degree of social consumption, the urbanisation rate, and others, (1) can be expanded as follows:

$$isu_{it}=a+\beta \mathrm{dig}_{it}+\lambda_1 \mathrm{open}_{it}+\lambda_2 fdi_{it}+\lambda_3 sc_{it}+\lambda_4 ubr_{it}+A_i+B_t+\mu_{it} \quad (2)$$

Where open denotes the degree of openness to the outside world, fdi represents the degree of financial development, sc indicates the degree of social consumption, and ubr signifies the urbanisation rate. λ_1, λ_2, λ_3, and λ_4 denote the coefficient of influence for the degree of openness to the outside world, the degree of financial development, the degree of social consumption, and the urbanisation rate respectively.

The imbalance and inadequacy in China's regional economic development have become a significant contradiction in the nation's current economic progress. In certain less developed regions, the digital economy may exhibit limited effects on industrial structure upgrading. Based on this, this paper posits that in regions where the industrial upgrading effect of digital technology is not pronounced, certain threshold variables may exist. Failure to meet these threshold variables hinders the realisation of the digital economy's potential. Therefore, this paper selects the level of economic development as the threshold variable (measured using the logarithm of per capita GDP). Employing Hansen's threshold panel model, the single threshold model is set as:

$$y_{it}=a+\beta_1 x_{it} I(q_{it}\le\gamma_1)+\beta_2 x_{it} I(\gamma_1\le q_{it}\le\gamma_2)+\beta_3 x_{it} I(q_{it}>\gamma_2)+\mathrm{A_i}+\mathrm{B_t}+\mu_{it} \quad (3)$$

#

Where y denotes the dependent variable, x represents the core explanatory variable, β_1 and β_2 denote regression coefficients, q signifies the threshold variable, γ indicates the threshold value, I is the indicator function (taking values of 1 or 0), a represents the constant term, and μ denotes the random error term.

4.2 Variable Selection and Explanation

4.2.1 Dependent variables

Drawing upon the estimation methodology of scholars Sun et al. [15], industrial structure upgrading is measured by the proportion of output value across the three sectors. Specifically, coefficients of 1, 2, and 3 are assigned successively to the primary, secondary, and tertiary industries. The industrial structure upgrading level index (ISU) is constructed based on the output value proportions and their respective weights as follows:

$$isu=\sum_{k=0}^{3} q_k \times k \quad (4)$$

Where q_k denotes the proportion of the kth industry's value-added in total output value. The ISU value ranges from [1,3], with values closer to 3 indicating a higher level of industrial structure upgrading in the region.

4.2.2 Core explanatory variable

In this study, the core explanatory variable is measured by the degree of digital technology development (hereafter, *dig*). Currently, there is no authoritative academic definition of digital technology, and its measurement methods vary considerably. Given the rich conceptual nature of digital technology, a single indicator struggles to capture its specific development level. This study employs the entropy method to measure digital economic development indicators (see Table 1 for details).

Table 1. Entropy Methodology for Constructing the Digital Economy Comprehensive Development Index System

Primary Indicators	Secondary Indicators	Tertiary Indicators	Weight
Comprehensive Digital Economy Comprehensive Development Index	Internet penetration rate	Number of Internet Users per 100 People	0.080
	Number of internet-related employees	Percentage of Computer Services and Software Employees	0.143
	Internet-related output	Telecommunications service volume per capita	0.298
	Mobile internet users	Mobile telephone users per 100 persons	0.074
	Digital Financial Inclusion Development	China Digital Inclusive Finance Index	0.406

Given data availability at the city level, this study measures the comprehensive development of the digital economy by leveraging two key dimensions: internet development and digital financial inclusion. For assessing internet development at the city level, drawing upon the methodology of Huang et al. [16], using four indicators, which are: the number of broadband internet users per hundred people; the proportion of employees in computer services and software industries relative to total urban unit employees; the total volume of telecommunications services per capita; and the number of mobile telephone users per hundred people. For digital financial development, the China Digital Inclusive Finance Index is employed, jointly compiled by Peking University's Digital Finance Research Centre and Ant Financial Group. The aforementioned data primarily originates from the China Urban Statistical Yearbook, the Peking University Digital Inclusive Finance Index, the National Bureau of Statistics, and provincial statistical yearbooks.

4.2.3 Threshold variables and control variables

Level of economic development (lnGDP) serves as a crucial threshold variable determining whether digital technology can empower industrial structure upgrading. This paper employs per capita GDP to measure regional economic development levels. Four control variables were selected: level of openness (open), level of financial development (fdi), level of social consumption (sc), and urbanisation rate (ubr). Specific calculation methods are detailed in Table 2 on the following page.

4.2.4 Data sources, variable calculation methods, and descriptive statistics

Table 2. Descriptive Statistics and Calculation Methods for Variables

Variable Name	Calculation Method	Obs	Mean	Std. Dev.	Min	Max
isu	$isu=\sum_{k=0}^{3} q_k \times k$	300	2.374	0.129	2.166	2.836
dig	Entropy Method	300	0.373	0.174	0.077	0.982
open	Actual Foreign Capital Utilisation/GDP	300	0.021	0.015	0	0.08
FDI	Total deposits and loans/GDP	300	3.233	1.15	1.518	8.131

sc	Total Retail Sales of Consumer Goods/GDP	300	0.382	0.067	0.222	0.603
ubr	Urban population/Total population	300	0.583	0.132	0.228	0.896
lnGDP	Logarithm of GDP per capita	300	10.833	0.444	9.706	12.013

Given data availability, this study employs ten-year statistical data (2011–2020) from 30 provinces and municipalities, excluding Tibet. All data originate from the National Statistical Yearbook and provincial statistical yearbooks. Descriptive statistics for variables are presented in Table 2.

5. Empirical Results Analysis

5.1 Analysis of Main Regression and Threshold Model Results

Table 3. Main Regression Results

Variable	isu (1)	isu (2)
dig	0.328*** (0.0244)	0.153*** (0.0307)
fdi		0.0242*** (0.0086)
sc		0.328*** (0.0928)
ubr		0.401* (0.231)
open		-0.219 (0.3030)
Time Fixed Effect	Control	Control
Individual fixed effects	Control	Control
_cons	2.252*** (0.0091)	1.884*** (0.107)
N	300	300

Note: * denotes p<0.1, ** denotes p<0.05, *** denotes p<0.01; figures in parentheses indicate standard errors.

Table 3 indicates that whether putting in control variables, the digital economy exerts a positive influence on industrial structure upgrading, playing a significant role in this process. However, given China's national context of uneven and insufficient economic development, an important question arises: does the level of economic development moderate the impact of the digital economy on industrial upgrading? Consequently, this study introduces per capita GDP as a threshold variable to test the hypothesis that the effect of the digital economy on industrial upgrading may attenuate when regional economic development is below a certain threshold. We employ threshold regression analysis to examine this non-linear relationship. The corresponding results are presented in Tables 4 and 5.

Based on the threshold effect test results in Table 4, the industrial structure upgrading model failed the triple-threshold and dual-threshold tests but passed the single-threshold effect test. The threshold value for economic development level is 9.8889. The single-threshold test results are reported below (Table 5).

Table 4. Threshold Effect Existence Test

Dependent Variable	Threshold Variable	Test Type	F-value	P-value	Threshold value
Industrial Structure Upgrading Index	Level of Economic Development	Single Threshold	38.54	0.0340**	9.8889
		Double threshold	15.81	0.3840	10.6632
		Triple threshold	9.94	0.6800	10.8585

Note: P-values are derived from 500 bootstrap resampling iterations, with ** denoting a 5% significance level.

Table 5. Threshold Model Regression Results

Variable Name	Isu (with economic development level as single threshold)
fdi	0.0239*** (0.00864)
sc	0.317*** (0.0926)
ubr	0.504*** (0.169)
open	-0.193 (0.307)
digI (lnG≤ 9.8889)	-0.014 (0.457)
digI (lnG> 9.8889)	0.142*** (0.0265)
_cons	1.901*** (0.115)
N	300
R2	0.854

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels respectively; figures in parentheses represent standard errors.

Table 6 indicates that the extent to which the digital economy promotes industrial upgrading is divided into two distinct intervals by the threshold variable of per capita GDP, with significant differences observed between these intervals. When the logarithm of per capita GDP is less than 9.8889, the digital economy exhibits no significant effect on industrial upgrading. Conversely, when the logarithm of per capita GDP exceeds 9.9889, the digital economy exerts a positive promotional effect on industrial upgrading. This indicates that the digital economy's effectiveness hinges upon the region possessing a certain industrial foundation. When combined with digital technologies, this industrial base generates new production methods and models, thereby driving industrial structure upgrading. In less economically developed regions, the application scenarios for digital technologies are limited, and the conditions for digital economic development are absent, thus preventing it from fully exerting its influence.

5.2 Heterogeneity Test

The threshold effect analysis indicates that the digital economy's promotion of industrial upgrading is influenced by the level of economic development. Considering the reality of uneven and inadequate economic development between eastern and western China, this study divides provinces into eastern, central, and western regions for regression analysis to test for heterogeneity. Given the limited data availability in Northeast China (comprising only Liaoning, Jilin, and Heilongjiang provinces), this region is temporarily excluded from the regression. Table 6 presents the results of the heterogeneity test:

Table 6. Heterogeneity Test Results

Variable Name	isu (East)	isu (Central)	isu (Western)
dig	0.134*** (0.0224)	0.00301 (0.130)	0.114 (0.117)
fdi	0.030*** (0.00547)	-0.0210 (0.0284)	0.0385* (0.0189)
sc	0.163 (0.126)	0.533** (0.178)	0.088*** (0.003)
ubr	0.492** (0.163)	1.466* (0.572)	0.312 (0.670)
open	-0.570** (0.254)	-1.600** (0.464)	-2.387* (1.247)
_cons	1.906*** (0.061)	1.429*** (0.187)	2.005*** (0.261)
Time effect	Fixed	Fixed	Fixed
Individual effect	Fixed	Fixed	Fixed
N	300	300	300
R^2	0.854	0.958	0.807

Note: *, **, ** denote significance at the 10%, 5%, and 1% levels respectively; standard errors are indicated in parentheses. Eastern, Central, Western, and North-Eastern regions are delineated according to National Bureau of Statistics classification standards.

The aforementioned regional heterogeneity tests reveal that the digital economy in the Eastern region demonstrably promotes industrial structure upgrading, whereas its impact in the Central and Western regions is insignificant. This finding broadly aligns with the threshold effect test results. This may be attributable to the relatively rapid pace of digital economic development in the eastern regions, where increased capital substitution for labour in the primary sector has enabled substantial labour outflows from this sector to be reallocated to emerging service sector positions created by the digital economy. This facilitates coordinated development between the primary and tertiary sectors, thereby promoting industrial structure upgrading and optimisation.

5.3 Robustness Tests

5.3.1 Regression using the 2SLS method

To mitigate the bias introduced by endogeneity in the model, this study employs the two-stage least squares (2SLS) method to re-regress the aforementioned issues. The instrumental variables selected draw upon the methodologies of Huang et al. [16] and Guo et al. [17] the digital economy centres on digital technologies, which represent an extension and evolution of fixed-line telephone communication technologies. Given their strong correlation and the negligible impact of fixed-line telephone usage on industrial upgrading, mobile phone penetration rates (units per hundred persons) across provinces from 2011 to 2020 were employed as instrumental variables for digital economic development. The regression results are presented in Table 7 below.

Table 7. 2SLS Regression Results

Variable	dig	ISU
dig		0.280***

		(0.0373)
fdi		0.0460*** (0.00376)
sc		0.105** (0.0453)
ubr		0.304*** (0.0412)
open		0.995*** (0.264)
Provincial mobile phone penetration rate (units per hundred persons)	0.487*** (0.0412)	
_cons	-1.995*** (0.153)	1.883*** (0.023)
N	300	300
F	130.882	130.882

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels respectively; standard errors are shown in parentheses.

As the number of instrumental variables in this paper matches the number of endogenous variables, only the issue of weak instrumental variables was examined, with no over-identification test conducted. The results show an F-value of 130.882, substantially exceeding 10. This indicates no weak instrumentation problem exists, confirming the model specification is sound. The regression results demonstrate that the digital economy maintains a significant positive correlation with industrial structure upgrading. This suggests that, after controlling for the endogeneity of digital technology, its positive impact on industrial structure upgrading remains statistically significant.

5.3.2 Adjusting the calculation method for the main variable

Following Guo et al. [17], robustness tests were conducted on the benchmark regression by altering the construction methods of the primary explanatory and dependent variables. Specifically, the industrial structure upgrading index was calculated using the ratio of the tertiary to secondary industries, while the digital economy index employed the same indicators as previously but calculated via principal component analysis. The regression results are presented in Table 8.

Table 8. Regression Results with Modified ISU and DIG Calculation Methods

Variable	isu
dig	0.301*** (0.0668)
fdi	0.211*** (0.0397)
sc	1.564*** (0.543)
ubr	-3.051** (1.316)
open	1.756 (1.793)
_cons	1.400*** (0.633)
N	300
R^2	0.804

Note: *, **, *** denote significance at the 10%, 5%, and 1% levels respectively; standard errors are shown in parentheses.

The regression results in the second column indicate that the digital economy continues to exert a significant positive effect on industrial structure upgrading.

5.3.3 Truncation and censoring

To mitigate the influence of outliers on model outcomes, this study applied both trimming and truncation to the main regression dataset. Specifically, the top 1% and bottom 1% of observations were replaced with values at the 1st and 99th percentiles, respectively. Table 9 demonstrates that key regression coefficients remain largely consistent with the primary regression results.

Table 9. Fixed-Effects Regression Results with Tail Trimming and Truncation

Variable Name	Isu (Truncation)	Isu (Truncation)
dig	0.150*** (0.0360)	0.144*** (0.0428)
fdi	0.0250*** (0.00854)	0.0254*** (0.00859)
sc	0.340*** (0.0923)	0.346*** (0.0907)
ubr	0.401 (0.249)	0.466* (0.244)
open	-0.222 (0.301)	-0.125 (0.288)
_cons	1.878*** (0.116)	1.834*** (0.116)
N	300	275
R^2	0.836	0.842

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels respectively; standard errors are shown in parentheses.

Following tailing and truncation as per Table 9, it is evident that the key regression coefficients remain consistent with the primary regression model, which continues to demonstrate robustness.

6. Conclusions and Implications

6.1 Conclusions

This study employs a fixed-effects panel model combined with a threshold regression approach, utilizing data from 30 Chinese provinces spanning 2011 to 2020, to investigate the impact of digital economy development on industrial structure upgrading. Regional heterogeneity analysis is further conducted, and robustness of the findings is verified through multiple methodological checks. The main conclusions are as follows: First, at the national level, digital economy development significantly promotes industrial structure transformation and upgrading across provinces. Second, regional analysis reveals that the digital economy substantially enhances industrial upgrading in eastern regions, while its effect in central and western regions is statistically insignificant. Finally, the level of regional economic development acts as a critical threshold variable; specifically, the influence of the digital economy on industrial upgrading exhibits a single threshold effect, with the estimated threshold value at 9.8889.

6.2 Implications

First, strengthen digital infrastructure development and vigorously advance the industrial internet. In regions with high internet penetration, further expand and upgrade regional networks by replacing outdated or inefficient fibre-optic lines, increasing broadband capacity, and enhancing network service quality. Accelerate foundational development in hardware, software, talent, and user bases to establish a robust foundation for the digital economy and provide sustained momentum for growth.

Second, tailored policies should be formulated to advance the digital economy, recognizing that optimal development pathways may vary significantly across regions. This study reveals significant heterogeneity in industrial economies between eastern and western regions. Adopting uniform policies and development guidelines across the board risks producing counterproductive outcomes. Therefore, when developing the digital economy in various regions, it is essential to integrate local natural geographical conditions and advantageous industries, enabling these strengths to better align with the digital economy and thereby drive the upgrading and optimisation of regional industrial structures.

Thirdly, robust economic development requires accelerating the integration of the digital and real economies. Governments and enterprises should promote the industrialisation of digital technologies, encourage corporate innovation, and guide the digital economy towards concrete industrial applications. This will foster the emergence of more emerging industries and create additional employment opportunities. Concurrently, digital technologies—including big data, the Internet of Things, and artificial intelligence—should be integrated into traditional industries to enhance labor productivity and propel industrial structures toward greater sophistication.

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