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Digital Economy, Governmental Intervention and Industrial convergence: Evidence from Henan, China

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Abstract

With a panel data of Henan Province in China from 2014 to 2021, this study examines the role and mechanism of the digital economy on the integration of advanced manufacturing and modern service industries and analyzes the moderating effect of governmental intervention on the direct effect path. The study found that: (1) Digital economy can seriously promote the integration of the two industries and has significant heterogeneity in developed areas, heartland and higher levels of marketization which perform more prominently; (2) The digital economy enables the integration of the two industries through two intermediary channels: improving technological innovation and reducing transaction costs, with the former accounting for a higher proportion of indirect paths; (3) Governmental intervention plays an inverted U-shaped moderating effect between the digital economy and the two industrial convergence: the relationship between the integration of the two industries and the digital economy is positively moderated when there is minimal government interference; When the intervention level is high enough, the relationship between the two is negatively regulated, even reversing the promoting effect between the two. The research conclusion is not only of great significance to understand the role of digital economy in China's economic transformation, but also provides a useful reference for policy makers in Henan Province.

Keywords

Digital Economy, Industrial Convergence, Technological Innovation, Transaction Cost, Government Intervention, Inverted U-Shaped Regulatory Effect

1. Introduction

In order to support China's industrial structure optimization and upgrading and to realize China's manufacturing industry's rising status in the global value chain, the industrial convergence is an inevitable decision. Industrial convergence has been described as a dynamic process of industrial convergence and evolution, referring specifically to the continuous emergence of new business forms and structural configurations through the interactive penetration of two or more industries (Lu, 2016). This study focuses on the convergence between advanced manufacturing and modern service industries (hereinafter referred to as "the two industries"). The 20th National Congress of China pointed out the need to "promote an in-depth melding of modern service industries with advanced manufacturing and modern agriculture". In recent years, the two industries' integration in China has deepened and intensified. However, it still faces problems such as insufficient depth, low level, institutional mechanisms and policy environment constraints. It is still necessary to strengthen the two industries' integration's leading and supporting roles in China's excellent social and economic development (Hu, 2023).

In today's era, digital technologies are the forerunners of the world's scientific and technical revolution and industrial change, as well as the key areas of a new era of global rivalry. Digital is becoming a core production factor to promote economic growth, and industrial convergence has become increasingly important in driving economic development. Data from "China Digital Economy Development Research Report (2023)" published by the China Communications Academy shows that in 2022, China's digital industrialisation scale got to 9.2 trillion yuan and the scale of industrial digitisation reached 41 trillion yuan, of which the digital economy penetration rate of the second and third industries was 24.0% and 44%. The gap between the penetration rate of the two industries was further narrowed, forming a pattern in which the digitalisation of industry and services is jointly driven. The digital economy is now a key component of industrial convergence and a growth driver. Additionally, the academic community generally believes that the economic rules of local government are the main reason for existing barriers to entry between different industries (Tadayoni & Skouby, 1999). When favourable external conditions arise owing to the introduction of supportive policies or deregulation by the government, enterprises try to continuously break the boundaries between different industries under the principle of profit maximization, resulting in the spillover of industrial functions, which enables the mutual integration of different industrial functions and supports the integration of industries. Hence, it can be said that government intervention is a favourable external guarantee for promoting deeper industrial convergence.

Despite the fact that the positive effects of the digital economy are expanding quickly in the application space, little is known about the mechanism underlying its influence, how the two industries integrate, and how the government plays into all of this. Is it possible for the digital economy to encourage the merging of these two sectors? If so, what steps can we take to encourage the two industries' integration? In the context of the digital economy, what part does the government play? None of these questions has been conclusively answered currently. Based on this fact, the following elements of this study's marginal contribution are represented. First, refer to the existing literature on the building and measurement of the digital economy index system and the integration of the two industries, explaining the factors affecting the integration of the two industries from different dimensions when discussing the relationship between the two industries, and further excavating the mechanism of the enabling effect of the digital economy on the growth of the integration of the two industries. Second, the two indicators of technological innovation, as well as transaction costs, are chosen as mediating variables to make clear the distinctive path of the digital economy to promote the integration of the two industries. Third, the indicator of government intervention is chosen as a moderating variable to analyze the role played by the government in the digital economy to empower the integration of the two industries.

2. Literature Review and Research Hypothesis

2.1. Direct Influence of the Digital Economy on the Integration of the Two Industries

The digital economy refers to a set of economic activities in which data resources are regarded as key factors of production, the modern information network serves as a crucial infrastructure, and the effective use of information and communication technology (ICT) acts as a major driving force to enhance efficiency and optimize economic structure (Xia et al., 2023). Firstly, the platform effect of the digital economy has fostered new business models and shifted consumer demands, driving integration between manufacturing and services. To meet diverse and personalized needs, manufacturers extend their value chains and incorporate upstream and downstream services, achieving "product + service" integration (Miao, 2021; Ma et al., 2025). Secondly, data resource sharing has become a key competitive strategy in industry integration. By leveraging big data and IT, manufacturers and service providers can gain greater profits and strengthen collaboration, thereby deepening integration (Büyüközkan & Göçer, 2018). Thirdly, digital elements' value-added impact drives industrial integration by empowering enterprises to reintegrate supply chain networks and enhance value creation through innovation chain optimization (Korder et al., 2024), which makes it possible for manufacturing and services to form a variety of combinations, enhances the ability of enterprises to create new products and services, and injects new momentum into for the integration of the two industries.

Hypothesis 1 (H1). The digital economy improves the integration of the two industries.

2.2. The Mechanism of Factors' Influence on the Integration of the Two Industries

Apart from the direct impact of the digital economy on the integration of the two industries under its characteristics, the essential features of the digital economy, which involve intertemporal transmission, exchange of data, and cost manufacturing and reduction, increase the likelihood that the digital economy will increase the integration of the two industries through internal factors such as technological innovation and transaction costs. The influence channels discussed above are shown in **Figure 1**.

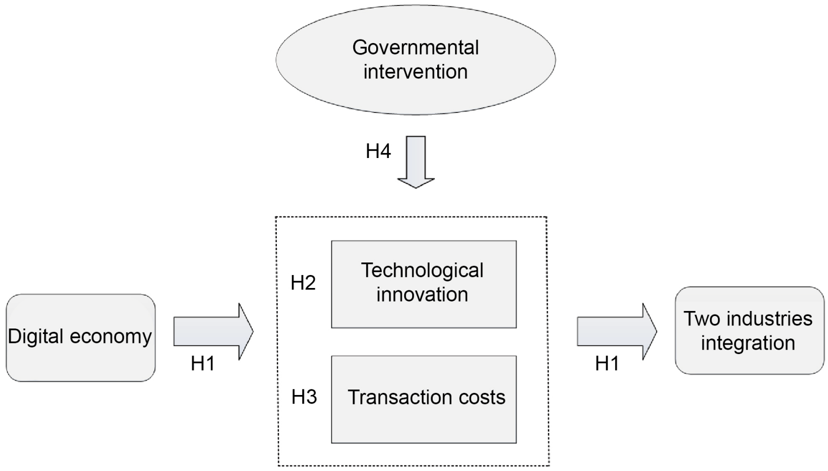

Figure 1. The impact and moderation mechanisms of digital economy on the integration of advanced manufacturing and modern service industries.

(1) Technological innovation. The digital economy mainly promotes technological innovation through the factor reorganization effect, market competition effect and knowledge spillover effect, and thereby improves the integration level of the two industries. On the one hand, digital technologies enhance the efficient flow and allocation of production factors, optimize enterprise resource utilization, and serve as a foundation for technological innovation (Tian et al., 2023). On the other hand, the digital economy also facilitates knowledge spillovers, enabling employees to access and absorb external knowledge more effectively, thereby strengthening firms' capabilities for personalized services and product innovation (Song, Ming, & Wang, 2013; Li, Ye, & Zhang, 2023). Moreover, digital finance and skilled labor matching further improve innovation efficiency and promote the transformation of manufacturing towards service-oriented models (Del Giudice et al., 2019; Tao et al., 2018). Technological innovation, in turn, drives the convergence of manufacturing and services by blurring industry boundaries and fostering common technical foundations, ultimately reinforcing industrial convergence (Lei, 2000).

Hypothesis 2 (H2). The digital economy boosts the integration between the two industries by increasing the level of technological innovation.

(2) Transaction costs. The digital economy mainly improves the level of integration between the two industries by reducing transaction costs through such channels as shortening the time-space distance, developing dynamic pricing strategies, changing the structure of transaction costs, and building a digital credit system. Firstly, it reduces intermediate costs. Digital technologies shorten spatial-temporal gaps between production and consumption, replacing traditional vertical hierarchies with platform-based models that streamline intermediary links (Li

& Zhao, 2024). Secondly, it reduces the costs of decision-making, bargaining and information search. By refining information flow and implementing dynamic pricing, digital systems eliminate reliance on fixed pricing mechanisms, enabling precise customized pricing and reducing costs arising from information asymmetry, bounded rationality, and opportunistic behavior (Liu et al., 2024; Wang et al., 2024). Thirdly, it reduces the matching cost. Internet technologies near-eliminate market research expenses, revolutionizing transaction cost structures through efficient product-service matching (Liu et al., 2022). Fourthly, it reduces the cost of trust. Algorithmic transparency and digital credit systems enhance product/service visibility, reducing supply-demand trust barriers and increasing consumer confidence (Lu et al., 2020). Transaction cost reduction establishes sustainable mechanisms for manufacturing-service sector interaction by accelerating industrial synergy integration (Eswaran & Kotwal, 2002; Liu et al., 2017). As Liu et al. (2022) confirm, digital technologies achieve this through cost-lowering effects that drive sectoral convergence. Therefore, the present paper puts forth the following hypotheses:

Hypothesis 3 (H3). The digital economy stimulates the integration of the two industries by lowering transaction costs.

2.3. Digital Economy, Government Intervention and the Integration of the Two Industries

From the standpoint of national conditions in China, the development of the digital economy and the integration of manufacturing and services are closely tied to the actions of local governments. Tools such as financial subsidies, tax adjustments, regulations, and industrial policies have long been key drivers of China's economic growth. Government intervention plays a vital role in both the integration of these two industries and in supporting digital economic activities. The integration process must navigate various external uncertainties, making digital support essential. Government policies align with this need by enhancing the ability to respond to external changes. Research supports this view: government intervention significantly impacts the productive service sector (Jiang & Shi, 2023); fiscal subsidies can accelerate the digital transformation of manufacturing (Sun, Sun, & Wang, 2024); and the Internet's impact on service industries is influenced by government actions (Xu et al., 2023). Moreover, government involvement shapes the role of manufacturing within the digital economy (Li, Zhang, & Li, 2024). However, excessive government intervention can lead to inefficient resource allocation and may negatively affect the integration of the two industries. Therefore, this article argues that there may be a nonlinear regulatory effect from government interference between the digital economy and the merging of the two industries.

Firstly, the development of the digital economy depends heavily on strong digital infrastructure, efficient resource allocation, and skilled talent. These elements require active government involvement. Through initiatives such as special funding, support for platform-based and diversified digital markets, enhancement of platform search and matching capabilities, and high-level talent programs, the government provides essential support for digital infrastructure, driving the growth of the digital economy (Liang & Li, 2023). At the same time, data—while a key competitive asset for digital platforms—can be misused by monopolistic players to block data flow, distort resource allocation, compromise consumer privacy, and reduce the effectiveness of digital technologies in meeting consumer needs. Government intervention through anti-monopoly regulation and digital taxation helps address these market failures and supports the healthy integration of digital technologies into industry (Li, Li, & Tao, 2023). Moreover, moderate deregulation is a prerequisite for integrating the digital and real economies. It facilitates more efficient resource use, encourages market competition, and fosters innovation, leading to new models and forms of industrial convergence (Pan, Huang, & Jin, 2023; Zhang & Zhao, 2024; Porter, 1980). However, excessive government intervention can lead to diminishing returns. Beyond a certain point, it may distort market resource allocation, hinder innovation, and disrupt the integration of digital and traditional industries. Thus, striking the right balance in intervention is crucial for promoting both digital economy growth and industrial integration.

Hypothesis 4 (H4). Government intervention plays an inverted U-shaped regulatory role between the digital economy and the two industries integration. Specifically, when the level of government intervention is small, it positively moderates the connection between the digital economy and the two industries integration; the relationship is negatively moderated when government intervention is large.

3. Data and Methodology

3.1. Model Construction

Benchmark model. To confirm how the digital economy affects the integration of the two industries, we set up the following benchmark regression model:

$$ic_{it} = \beta_0 + \beta_1 dige_{it} + \beta_k X_{it} + \delta_t + \theta_i + \varepsilon_{it} \quad (1)$$

In Equation (1): i,t and ic_{it} describe the province, the year and the integration of the two industries, respectively. $dige_{it}$ is the digital economy. X_{it} represents control variables. In addition, δ_t and θ_i represent the time-fixed effect and city-fixed effect respectively, and ε_{it} signifies the random error term.

Mediation model. We build the following effect mediation models to test whether technological innovation is the mechanism via which the integration of the two industries is impacted by the digital economy:

$$innov_{it} = \beta_0 + \beta_2 dige_{it} + \beta_k X_{it} + \delta_t + \theta_i + \varepsilon_{it} \quad (2)$$

$$ic_{it} = \beta_0 + \beta_3 innov_{it} + \beta_4 dige_{it} + \beta_k X_{it} + \theta_i + \delta_t + \varepsilon_{it} \quad (3)$$

In Equation (2) and (3): $innov$ is technological innovation; if the digital economy can facilitate the integration of the two industries by improving the technological innovation, then $\beta_2 > 0$ and $\beta_3 > 0$.

Mediation model. We constructed effect mediation models to test whether transaction costs are the means by which the digital economy influences the two industries' integration:

$$cost_{it} = \beta_0 + \beta_5 dige_{it} + \beta_k X_{it} + \delta_t + \theta_i + \varepsilon_{it} \tag{4}$$

$$ic_{it} = \beta_0 + \beta_6 cost_{it} + \beta_7 dige_{it} + \beta_k X_{it} + \delta_t + \theta_i + \delta_t + \varepsilon_{it} \tag{5}$$

In Equation (4) and (5): $cost$ is transaction cost; if the digital economy reduces transaction costs and promotes integration between industries, then $\beta_5 < 0$ and $\beta_6 < 0$.

Moderating model. We construct the moderating effect model to study the moderating connection of government intervention on the digital economy's influence on the integration of the two industries. Referring to (Haans, Pieters, & He, 2016; Miller, Stromeyer, & Schwieterman, 2013), the following moderating effect models are constructed by introducing $dige_{it} \times gov_{it}$ and $dige_{it} \times gov_{it}^2$:

$$ic_{it} = \beta_0^2 + \beta_1^2 dige_{it} + \beta_2^2 gov_{it} + \beta_3^2 dige_{it} \times gov_{it} + \beta_4^2 X_{it} + \delta_t + \theta_i + \varepsilon_{it} \tag{6}$$

$$\begin{aligned} ic_{it} = {} & \beta_0^3 + \beta_1^3 dige_{it} + \beta_2^3 gov_{it} + \beta_3^3 dige_{it} \times gov_{it} \\ & + \beta_4^3 dige_{it} \times gov_{it}^2 + \beta_5^3 X_{it} + \delta_t + \theta_i + \varepsilon_{it} \end{aligned} \tag{7}$$

In Equations (6) and (7): gov represents government intervention. If R^2 of the model (7) is greater than that of the model (6), it indicates that government action has a moderating effect on the integration of the two industries. If $\gamma_3^3 > 0$ and $\gamma_4^3 < 0$, passing the significance test of the coefficient, it can be demonstrated that government intervention has an inverted U-shaped moderating role in the effects of the digital economy on the merger of the two industries. And in the econometric regression results, the partial derivative of the digital economy ($dige_{it}$) on the two industries integration (ic_{it}) is the adjusting effect of government intervention on the connection between the two is reflected in the ($\beta_1^3 + \beta_2^3 gov_{it} + \beta_4^3 gov_{it}^2$).

3.2. Variable Description

Explained variable. Integration of the two industries ic. To ensure a scientific and systematic reflection of the development status of the two industries and to meet the matching and corresponding evaluation indicators of the two industries, we draw reference from Zhang et al. (2025) and use the coupled coordination model to quantify the degree of integration between two industries. The paper constructs first-level evaluation indicators from three aspects: industrial scale, industrial base and industrial structure. It selects 16 second-level indicators to create an assessment index system. Detailed indicators are displayed in **Table 1**.

Firstly, the advanced manufacturing industry and the modern service industry are first assessed for their respective levels of comprehensive development. The degree of coupling between the two industries is then determined by applying the coupling coordination model. The coupling coordination model is as follows:

$$C = 2\sqrt{U_1 * U_2 \big/ \left(U_1 + U_2\right)^2} \tag{8}$$

Table 1. Evaluation indicator system for comprehensive growth of advanced manufacturing and modern service industries.

Dimensionality	Advanced manufacturing industry	Modern service industry
Industrial scale	Delivery value of import and export	Foreign investment
	Investments in property, plant and equipment	Investments in property, plant and equipment
	Value added	Value added
Industrial basis	Main business income	Main business income
	Quantity of enterprises	Quantity of enterprises
	Quantity of employees	Quantity of employees
Industrial structure	Added value/Secondary sector contribution	Added value/Enhanced value in tertiary industry
	Employees/Secondary industry employees	Employees/Tertiary industry employees
	Fixed investments/Secondary industry fixed investments	Fixed assets investment/Fixed investments in tertiary industry

In Equation (8): U_1 and U_2 are comprehensive order parameters of the advanced manufacturing and modern service industry, and C is the system coupling degree of the two. The value of C is between 0 and 1. $U_1 = \sum_{j=1}^{n} \lambda_{1j} U_{1j}$, $U_2 = \sum_{j=1}^{n} \lambda_{2j}$; $\sum_{j=1}^{n} \lambda_{1j} = 1$, $\sum_{j=1}^{n} \lambda_{2j} = 1$; λ_{1j} and λ_{2j} are the index weight coefficients of the two subsystems respectively, which are obtained by entropy method here. The model for coupling coordination is as follows:

$$D = \sqrt{C * T} \tag{9}$$

In Equation (9): $D(0 \le D \le 1)$ is the coupling coordination degree of the two systems, which measures the level of integration between industries. A higher level of D means a higher level of integration between industries. T indicates the comprehensive coordination coefficient of the two industries. $T = \alpha * U_1 + \beta * U_2$, and $\alpha + \beta = 1$. α and β respectively refer to the proportion of advanced manufacturing and modern services, and $\alpha = 0.4$, $\beta = 0.6$.

We categorize the advanced manufacturing and modern services using classification standards from the State Administration of Taxation, the Ministry of Finance, and the '13th Five-Year Plan' Scientific and Technological Innovation and Transformation Plan for Modern Service Industry published in 2017.

Core explanatory variable. Digital economy $dige$. These eight indicators cover the core dimensions of industrial penetration, infrastructure and innovation capability of the digital economy. They complement each other and constitute a comprehensive and systematic evaluation framework, which can accurately reflect the development level of digital economy at the technical, industrial and social levels. Using SPSS software, factor analysis was used to perform dimensionality reduction on the eight indicators in Table 2, and two common factors with a cumulative contribution of 78.49% were obtained. After performing orthogonal rotation, the indicators can be classified into two categories based on their loadings on different factors. The first factor is digital infrastructure and innovation capability, including indicators such as mobile subscription, total telecommunications

Table 2. Relevant indicators of the extent of the digital economy.

Indicator name	Common factor name	Factor analysis	
Mobile subscription	Digital Infrastructure and Innovation Capacities	Measuring infrastructure and innovation systems	Development level of the digital economy
Total telecommunications business per capita			
Patent application number			
R&D expenditure of industrial enterprises above designated size			
Number of Internet broadband access users			
Length of long-distance optical cable			
Number of employees in information transmission, software and information technology services	The depth of digital industry application	Measure the effect of industrial penetration	
Digital inclusive finance			

business per capita, and patent application number. The second factor is the application depth of the digital industry, including the number of employees in information transmission, software and information technology services, and digital inclusive finance. The specific factor loading matrix is reported in **Table A1** of the Appendix. Finally, the advancement stage in the digital economy is calculated using the following formula:

$$dige = w_1 f_1 + w_2 f_2 \tag{10}$$

In Equation (10): w is the contribution rate of the factor and f is the component score coefficient of the factor.

Mediating variables. Technological innovation (innov). Patents contain valuable information about technology, inventions, and inventors, and can provide insight into the level of technological innovation. They are often used in research due to their accessibility and generalizability (Acs, Anselin, & Varga, 2002). This paper evaluates technological innovation by calculating the ratio of weighted patent filings relative to the overall population of a region. The weighted count of patent applications is calculated by considering three categories of patents: invention, utility and design patents. Each type is given a weight of 0.5, 0.3, and 0.2, respectively, based on their degree of innovation. This approach provides a more comprehensive and realistic reflection of each region's patent output level.

Transaction cost (cost). Transaction costs are the expenses involved in conducting economic transactions. In the study of Feng (2009), operating costs are used to measure transaction costs. While production operating expenses and transaction costs are not identical, they share a growth trend and can partially explain transaction costs. Variable substitution is a viable method.

Moderator variables. Government intervention (gov). In the paper, Zhao and Yan (2024) tested government intervention utilizing a percentage of fiscal expenditure to GDP in each provincial and municipal area, with a higher ratio indicating stronger government intervention and vice versa.

Control variable. We took into account the following variables that might have an impact on the integration of the two industries when testing the hypotheses. Economic development (pgdp) is assessed by GDP per capita; Foreign investment (foin): is defined as the total level of foreign investment in each region during the current year; Infrastructure (asset): quantify the ratio of fixed asset investment to regional GDP; Industrial structure (indu) is quantified as the percentage of the gross product of the tertiary sector to the gross product of the secondary sector; Resident income (wage) is the average wage of residents.

Data sources and descriptive statistics. This paper makes panel data from 17 perfecture-level city between 2014 and 2021. The data are taken from Henan Tertiary Industry Statistical Yearbook and National Bureau of Statistics. Missing data is interpolated using the linear interpolation method.

Table 3 gives the descriptive statistical outcomes for the main variables. The mean value of ic is 0.348, with variances of 0.151. Thus, the level of integration of the two industries has some variations. The mean and variance values of the digital economy are 0.016 and 0.937, respectively, showing that there are significant variations in digital economics across different provinces. Conversely, the values are within a respectable range, as shown by the descriptive statistics of the moderator, mediating and control variables.

Table 3. Summary statistics.

Variables	N	Mean	Std. Dev	Min	Max
ic	136	0.348	0.151	0.068	0.921
dige	136	0.016	0.937	−1.085	7.071
innov	136	1752.179	3426.335	108.000	22741.500
cost	136	112.333	53.360	21.75	238.280
gov	136	1607.107	339.477	946.063	2312.550
pgdp	136	44129.700	17699.840	15734.000	113139.000
indu	136	0.817	0.322	0.256	1.649
wage	136	94.000	54.126	1.000	187.000
asset	136	11.579	20.604	0.811	117.325
foin	136	41.457	30.089	9.546	282.721

We test for multicollinearity by calculating the variance inflation factor (VIF) for all predictor variables. As shown in Table A2 of the Appendix, all VIF values are far below the threshold of 10, indicating that multicollinearity is not a problem in this model.

4. Empirical Analysis

4.1. Baseline Regression Analysis

This research takes a general-to-specific strategy to examine how the digital economy and different control variables have an impact on the integration of the two industries. We begin by conducting a regression analysis on the core explanatory and explained variables, followed by the gradual addition of control variables. Table 4 summarizes the regression findings.

Table 4. Baseline regression results.

variable	(1)	(2)	(3)	(4)	(5)	(6)
	ic	ic	ic	ic	ic	ic
dige	0.102^{***}	0.128^{***}	0.139^{***}	0.148^{***}	0.150^{***}	0.135^{***}
	(2.79)	(3.60)	(4.07)	(5.21)	(5.50)	(4.56)
pgdp		0.221^{***}	0.204^{***}	0.176^{***}	0.180^{***}	0.200^{***}
		(3.44)	(3.32)	(3.45)	(3.67)	(3.87)
foin			-0.111^{***}	-0.084^{***}	-0.090^{***}	-0.091^{***}
			(−3.45)	(−3.12)	(−3.49)	(−3.50)
asset				-0.123^{***}	-0.100^{***}	-0.105^{***}
				(−7.15)	(−5.53)	(−5.66)
indu					-0.076^{***}	-0.067^{***}
					(−3.20)	(−2.75)
wage						−0.070
						(−1.19)
Constant	-0.207^{***}	−0.056	-0.081^{***}	-0.176^{***}	-0.235^{***}	-0.325^{***}
	(−5.15)	(−0.95)	(−17.03)	(−3.59)	(−4.65)	(−3.58)
Observations	136	136	136	136	136	136
R-squared	0.599	0.638	0.674	0.779	0.798	0.801
City FE	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes

Note: *, **, and ***respectively represent significance at the significance level of 10%, 5%, and 1%, with the t-statistic of the estimate in parentheses. The same applies hereinafter.

The correlation between the digital economy and the integration of the two industries is displayed in Table 4 by the information displayed in Column (1). The coefficients of dige are considerably positive at the level of 1%, showing that the digital economy can improve the integration of the two industries. Control variables are shown in Columns (2) through (6) of the regression observations. The dige coefficients are significantly positive, implying that the parameter estimates for the core explanatory variables are robust. This further confirms the value of digital economy in facilitating the integration of the two industries. Therefore, hypothesis 1 is valid. The above results offer theoretical guidence for Henan Province to accelerate the new kinetic energy by integrating the two industries and accelerating the digital economy. Digital economy is developing quickly due to the widespread use of new-generation information technologies like cloud storage, 5G, large amounts of data, the internet, and robotics, and continuous breakthroughs and innovations are made in terms of development speed, development scale and scenario application, providing impetus and ideas for two industries to overcome the value chain's "low-end lock" conundrum.

The estimated coefficient of economic development during the data collection period is positive and passes the significance degree test of 1%, according to **Table 4**'s empirical assessment of the control variables in Columns (6). This suggests that a feasible external economic environment is provided by the level of economic development for the integration of the two industries. Foreign investment has a favorable effect on the integration of the two industries, as indicated by the estimated coefficient of the level of foreign investment, which is significantly positive. The reason may be that the cooperation between foreign trade enterprises and domestic reproduction, research and development, sales and so on, makes the whole value chain more complete and orderly. Through cooperation with foreign enterprises, domestic enterprises continuously improve their position and added value in the industrial chain, and then open up new potential for the integration of the two industries. The estimated coefficient of fixed assets is significantly negative, which inhibits the integration of the two industries. The reason may be that the specificity of fixed assets is strong, and the cost of reconfiguring these assets for service-related business activities is high. The calculated coefficient of industrial structure is notably negative, revealing that, to some extent, an increase in the share of secondary industry raises the need for technical innovation in production processes and processes, thus inhibiting the integration of the two industries. The conclusion that raising residents' living conditions unilaterally will not be sufficient to effectively promote the merger of the two businesses is supported by the calculated coefficient of residents' income, which is not substantial.

4.2. Endogeneity and Robustness Checks

Endogeneity tests. The digital economy and the merging of the two sectors might be causally related in both directions. On the one hand, the digital economy fosters the deep integration of the two industries is by facilitating the movement of factors between regions through platform, sharing, and value-added effects. On the other hand, regions with a high degree of integration of the two industries tend to have a more complete industrial system. Additionally, the level of digital economic innovation ability and digital infrastructure affects the development and diffusion process of digital technology, which in turn impacts the level of industrial digitalization. Referring to the practice of Nunn and Qian, this paper utilizes the method of instrumental variables to handle potential endogeneity issues, such as two-way causality (Nunn & Qian, 2014). An instrumental variable for the digital economy is the interaction term between the number of landline phones per 100 persons in each city in 1984 and the total number of Internet broadband ports in Henan from 2014 to 2021. The specific regression results are provided in **Table A3** of the Appendix. This variable is then put via 2SLS regression. The Kleibergem-Paap rk LM statistic in **Table A3**'s Column (1) demonstrates that it has a level of statistical significance of 1%, meaning that the chosen instrumental factors are not inadequately identified. Weak instrumental variables do not present a concern, as indicated by the Cragg-Donald Wald F statistics, which is greater than the 10% crucial value. The digital economy's regression coefficient for the integration of the two industries is noticeably positive, suggesting that endogeneity does not compromise the validity of the baseline regression findings.

Robustness test. The specific regression results are provided in Table A3 of the Appendix. First, we replace the core explanatory variable. By reconstructing the early digital economy indicators and applying the entropy method instead of factor analysis, we reassess the impact of the digital economy on industrial integration. The results in Column (2) of Table A3 are consistent with the baseline regression. Second, we replace the estimation method. To avoid potential serial autocorrelation caused by the cumulative effect of industrial integration, we adopt the system GMM model within a dynamic panel framework. Column (3) of Table A3 demonstrates that the regression coefficient of the digital economy on two-industrial convergence is remarkably positive, and the model's validity and stability are supported by the findings of the Hansen and AR tests. Further validating the accuracy of the system GMM results are the results in column (4) of Table A3, which use the one-period delayed digital economy as an instrumental variable for the 2SLS regression. Both methods confirm the robustness of the above results. Finally, Removal of outliers. This study uses a 1% and 99% shrinkage in the tail for sample variables to test whether the sample outliers have a meaningful effect on the outcomes. According to Table A3's column (5) data, the estimated coefficient of the two industries' integration in facilitating the digital economy is still significantly positive, which is in line with earlier findings.

4.3. Heterogeneity Analysis

The specific regression results are presented in Table A4 of the Appendix. First, heterogeneity in economic development. Cities differ significantly in economic foundation, digital infrastructure, and labor quality. To explore this, the 17 cities in Henan are divided into 9 developed and 8 underdeveloped cities based on 2021 GDP rankings. Columns (1) and (2) in Table A4 show that the digital economy significantly promotes industrial integration in developed cities. In contrast, although the coefficient remains positive in underdeveloped cities, it is not statistically significant. This may be due to weaker infrastructure, limited innovation capacity, and lack of policy support in those areas.

Second, heterogeneity in urban location. Based on adjacency to the provincial capital, the cities are grouped into 7 central and 9 peripheral cities. Results in Columns (3) and (4) show that the digital economy has a stronger effect in central cities. This may result from better infrastructure, higher innovation levels, and earlier digital transformation in central areas, whereas peripheral cities lag behind in these aspects.

Finally, heterogeneity in marketization level. A more developed market environment helps the digital economy allocate resources efficiently and promote integration. Using the marketization index by Fan Gang, regions are divided into high and low marketization groups. Columns (5) and (6) show that the digital economy significantly facilitates integration in highly marketized regions, but the effect is insignificant in regions with weaker market development. This suggests that inadequate market mechanisms may hinder the digital economy's role in driving industrial integration.

4.4. Mechanism Analysis

Mediating effect of technological innovation. Table 5, columns (2) and (3) examine the mediating influence of technological innovation. The findings reported in column (2) reveal that the digital economy has a considerably beneficial effect on technological innovation at the 1% level, implying that a higher level of digital economy growth is more conducive to technological innovation. The regression coefficient of technological innovation in column (3) is highly positive, suggesting that greater technological innovation can facilitate the integration of the two businesses. Simultaneously, the regression coefficient of the digital economy is found to be lower than that of column (1), indicating that technological innovation acts as part of the mediating the relationship between the integration of the two industries and the digital economy.

Numerically, the size of the mediating effect is about 0.043, which accounts for about 0.3196 of the total effect, indicating that technological innovation can explain 31.96% of the expanision of digital economy development in fostering the integration of the two industries. That is, the mechanism is "developing digital economy → improving technological innovation → promoting the integration of the two industries". In addition, the article carried out the sgmediation mediation effect test, the results show that the Sobel test, Goodman1 test and Goodman2 test are significant, so hypothesis hypothesis 2 is supported.

Mediating effect of transaction costs. In Table 5, columns (4) and (5) test the mediating effect of transaction costs. The regression coefficient of dige in column (4) is not positive and passes the significance level of 1%, indicating that the growth of the regional digital economy contributes to the reduction of transaction costs in the region. The data in column (5) indicate that generating more transaction costs is not favourable to the integration of the two industries, as the regression coefficient of transaction cost is strongly negative.

Additionally, the value of the digital economy decreases compared to the first step, implying that the digital economy and industrial convergence are partially mediated by transaction cost. The mediation effect is numerically 0.005, accounting for 3.6% of the total effect, indicating that transaction costs may account for the hindrance to the digital economy's growth in terms of the two industries' integration. The mechanism is "developing digital economy → decreasing transaction cost → improving integration of the two industries". In addition, the significance of the Sobel test, Goodman1 test, and Goodman2 test meet the requirements. We conducted a robustness test using the level of financial development as

Table 5. Regression results of mediating effect of technological innovation and transaction costs.

variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	ic	innov	ic	cost	ic	fd	ic
dige	0.135***	0.306***	0.092***	−0.056**	0.130***	0.321**	0.133***
	(4.56)	(3.83)	(3.14)	(−2.17)	(4.41)	(2.44)	(4.52)
innov/cost/fd			0.141***		−0.088***		0.0905***
			(4.19)		(−3.71)		(4.73)
pgdp	0.200***	0.619***	0.113**	0.387***	0.232***	0.170**	0.0120
	(3.87)	(4.44)	(2.16)	(3.63)	(4.26)	(2.19)	(0.69)
foin	−0.091***	−0.131*	−0.072***	−0.009	−0.091***	0.042	−0.002
	(−3.50)	(−1.89)	(−2.95)	(−0.17)	(−3.56)	(0.98)	(−0.21)
asset	−0.105***	−0.030	−0.101***	−0.135***	−0.116***	−0.176***	−0.0340***
	(−5.66)	(−0.61)	(−5.83)	(−3.53)	(−5.98)	(−3.99)	(−3.34)
indu	−0.067***	−0.344***	−0.019	0.141***	−0.056**	0.159	0.016
	(−2.75)	(−5.21)	(−0.75)	(2.78)	(−2.22)	(0.65)	(0.29)
wage	−0.070	−0.026	−0.066	0.604***	−0.020	−0.492***	−0.011
	(−1.19)	(−0.17)	(−1.22)	(5.01)	(−0.32)	(−8.46)	(−0.72)
Constant	−0.325***	−0.524**	−0.251***	0.886***	−0.252**	0.649***	0.263***
	(−3.58)	(−2.15)	(−2.92)	(4.74)	(−2.55)	(−3.05)	(5.50)
Observations	136	136	136	136	136	136	136
R-squared	0.801	0.883	0.829	0.606	0.806	0.5027	0.803
City FE	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes
Sobel test		0.0035*** (Z = 3.501)		0.024* (Z = 1.875)		0.0291**(Z = 2.165)	
Goodman1 test		0.0042*** (Z = 3.522)		0.034* (Z = 1.836)		0.0291**(Z = 2.128)	
Goodman2 test		0.0029*** (Z = 3.564)		0.038** (Z = 1.884)		0.0291**(Z = 2.204)	

a proxy variable for transaction costs. However, it is important to note that there is an inverse relationship between the level of financial development (fd) and transaction costs. In other words, transaction costs decrease as the level of financial development increases. By observing the regression results in columns 6 and 7 of Table 5, it was found that it significantly passed the robustness test. The hypothesis 3 is supported.

4.5. Adjustment Effect Analysis

According to the above theoretical analysis, the digital economy and the merging of the two sectors may be moderated by government involvement in the form of an inverted U. Based on the regression findings of columns (1) and (2) of Table 6, the value of the digital economy increases slightly after the government intervention index is added, but it remains highly positive, and the value of the regression model increases from 0.135 to 0.087. This implies that the relationship between

Table 6. Regression results of moderating effect.

variable	(1)	(2)	(3)	(4)	(5)
	ic	ic	ic	ic	ic
dige	0.135***	0.087***	0.093***	0.077***	0.066***
	(4.56)	(3.43)	(3.74)	(3.04)	(7.052)
gov		0.190***	0.196***	0.213***	0.137*
		(8.13)	(8.53)	(8.95)	(1.937)
dige*gov			0.056**	0.237***	0.246***
			(2.41)	(2.82)	(3.978)
dige*gov^2				−0.171**	−0.370***
				(−2.23)	(−4.863)
pgdp	0.200***	0.107***	0.123***	0.112***	0.001***
	(3.87)	(2.72)	(3.13)	(2.89)	(4.360)
foin	−0.091***	−0.018*	−0.019*	−0.017*	−0.006***
	(−3.50)	(−1.71)	(−1.85)	(−1.68)	(−14.778)
asset	−0.105***	−0.065***	−0.070***	−0.063***	−0.005***
	(−5.66)	(−4.05)	(−4.43)	(−4.02)	(−8.736)
indu	−0.067***	−0.040**	−0.029	−0.029	−0.137*
	(−2.75)	(−2.02)	(−1.46)	(−1.46)	(−1.937)
wage	−0.070	−0.023	0.062	0.071	0.046
	(−1.19)	(−0.49)	(1.08)	(1.26)	(0.620)
L. dige					0.730***
					(8.846)
Constant	−0.325***	−0.358***	−0.248***	−0.257***	−0.315*
	(−3.58)	(−4.91)	(−2.93)	(−3.09)	(−1.741)
Observations	136	136	136	136	136
R-squared	0.801	0.871	0.878	0.884	0.880
City FE	yes	yes	yes	yes	no
Year FE	yes	yes	yes	yes	no
AR (1)					0.000
AR (2)					0.684
Sargan test					0.986

the digital economy and the merger of the two industries is moderated by government involvement. Government intervention has a beneficial adjusting effect that only affects the magnitude of the positive spillover influence of the digital economy on the integration of the two sectors, but not its direction. However, the adjusting effect of government intervention increases the elasticity of the digital economy to the integration of the two industries, making it more sensitive to such integration. The determination coefficients of columns (3) and (4) show that model (4) is superior to model (3), indicating that government intervention has a nonlinear moderating effect. According to column (4)'s regression results, there is a significant positive correlation between the digital economy and government intervention, and a significant negative correlation between the digital economy and government intervention squared. It demonstrates how government action has an inverted U-shaped moderating influence on the relationship between the digital economy and the merger of the two industries. Specifically, a modest level of government intervention has a positive moderating effect on the digital economy and the integration of the two industries; that is, as government intervention increases, the positive impact of the digital economy on the integration of the two industries is somewhat amplified. When the government intervention continues to increase, the relationship between the digital economy and the integration of the two sectors is negatively moderated, that is, as the government intervention further increases and exceeds the optimum range, the government intervention weakens or even reverses the positive impact of the digital economy on the convergence of the two industries. So hypothesis 4 is supported.

Table 6's column (5) contains the dynamic GMM model's estimation results. The *P*-values of AR (1), AR (2) and Sargan assays imply that there is no second-order autocorrelation in the disturbance term and no over-identifying problem in the instrumental variables. The dynamic GMM model is in accordance with the previous regression analysis. The interaction term between the digital economy and government intervention square remains still significantly negative, indicating that the regression evidence continues to be robust, and the moderating role of government intervention remains inverted U-shaped. In addition, the estimated coefficient of the one-period lag of the digital economy is highly consistent and positive at the level of 1%, meaning that the digital economy of the previous period has a greatly positive impact on the growth level of the current digital economy. Therefore, it seems sense to incorporate the inertia effect into the model.

This paper draws a regulatory effect diagram to clearly observe the regulatory effect of government intervention. According to Table 6 column (4), the variables containing the digital economy in the regression model are merged into the same phase, as shown in formula (11). From the regression results of Column (4), $\beta_1^4 = 0.077$, $\beta_3^4 = 0.237$, $\beta_4^4 = -0.171$, it can be seen that the regression coefficients are substituted into Equation (11), and the regression models are all standardized regression models, and the inverted U-shaped adjustment effect diagram of government intervention is drawn, as shown in Figure 2. It can be seen that there is a threshold for the impact of government intervention. On the left side of the threshold, the slope of the relationship between the digital economy and the integration of the two industries continues to increase, indicating that the improvement of government intervention can strengthen the positive impact of the digital economy on the integration of the two industries. However, when government intervention exceeds a certain threshold, the slope of the relationship between the digital economy and the integration of the two industries begins to decline, and finally presents a negative impact on the integration of the two industries, indicating that government intervention weakens the positive impact of the digital economy on the integration of the two industries.

$$ic_{it} = \beta_1^4 + \beta_3^4 gov_{it} + \beta_4^4 gov_{it}^2 \quad (11)$$

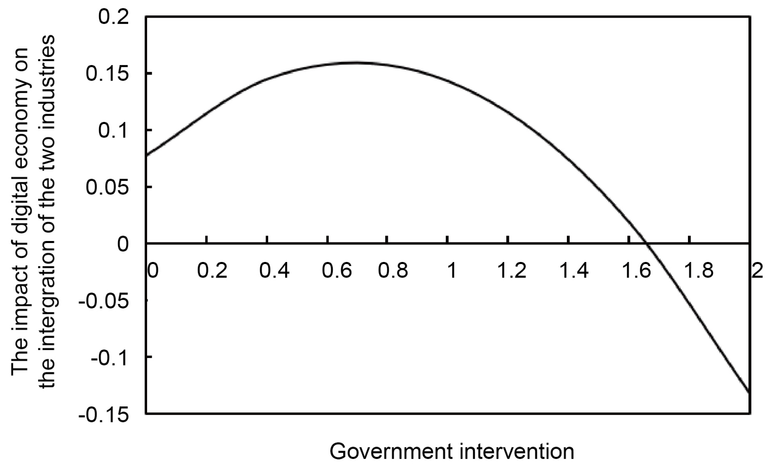

Figure 2. The inverted U-shaped moderating effect of government intervention.

5. Conclusion

Using the panel data of prefecture-level cities in Henan Province from 2014 to 2021, mediating, and moderating effects of the digital economy promote the integration of the two industries. It also reveals the mechanism by which the digital economy promotes the integration of the advanced manufacturing industry and modern service industry. The following are the primary conclusions:

Firstly, the direct effect shows that the development of the digital economy greatly fosters the integration of the two industries. Following the inherent concerns of the instrumental variable approach and robustness test, the substitution of key explanatory variables, the replacement of estimating techniques, and the removal of outliers, this conclusion remains true. Secondly, the impact of the digital economy on the integration of the two sectors is quite heterogeneous. The digital economy has a more significant role in fostering the integration of advanced manufacturing and modern services in developed areas, heartland and higher levels of marketization. Thirdly, the digital economy not only has direct effects but also indirectly fosters the merger of the two industries through two mediating channels: transaction cost reduction and technical innovation promotion. Compared with transaction costs, the indirect path of technological innovation accounts for a higher proportion, with positive and negative mediating effects accounting for 31.96% and 3.6% respectively. Fourthly, the inverted U-shaped regulatory effect of government involvement also has an impact on the interaction between the digital economy and the merger of two industries in the direct effect path. Low levels of government intervention have a positive impact on the relationship between the digital economy and the integration of two industries. This increases the elasticity of the digital economy to the integration of two industries, increases the sensitivity of the reflection, and partially strengthens the positive effect. When the degree of government intervention deepens and exceeds the optimal value, it negatively regulates the connection between the digital economy and the integration of the two industries, making the positive effect of the digital economy on the integration of the two industries weaken or even reverse to a certain extent.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

The part of the text that is not reported.

Table A1. Factor loading matrix after rotation (orthogonal rotation).

Variable	Factor 1	Factor 2	Uniqueness
Mobile subscription	**0.8351**	0.2316	0.2490
Total telecommunications business per capita	**0.8517**	0.4283	0.0911
Patent application number	**0.8801**	0.1828	0.1920
R&D expenditure of industrial enterprises above designated size	**0.7609**	0.0962	0.4117
Number of Internet broadband access users	**0.7951**	0.3916	0.2144
Length of long-distance optical cable	**0.6181**	0.2939	0.5316
Number of employees in information transmission, software and information technology services	0.2199	**0.9675**	0.0157
Digital inclusive finance	0.2083	**0.9702**	0.0154

The factor statistic: Factor 1 eigenvalue: 4.99; Factor 2 eigenvalue: 1.28; Variance explained by factor 1: 48.53%; Variance explained by factor 2: 29.96%; Cumulative explained variance: 78.49%; KMO test value: 0.786.

Table A2. Multicollinearity Test (VIF).

Variable	Baseline regression model	Mediation effect model		Moderating effect model
dige	3.47	4.19	3.51	5.06
Innov		3.03		
cost			1.14	
gov				1.41
dige*gov				1.15
dige*gov^2				2.28
pgdp	1.73	3.93	1.73	2.01
foin	1.43	1.45	1.44	1.65
asset	1.22	1.53	1.29	1.25
indu	3.29	4.95	3.30	3.52
wage	2.77	2.89	2.88	3.18
Mean VIF	2.32	3.14	2.19	2.39
Observations	136	136	136	136

Note: 1) All VIF values were < 6. 2) Interaction variables have been centralized processing. 3) gov^2 represents the quadratic term of government intervention.

Table A3. Test of endogeneity and robustness of the model.

Variable	Endogeneity concerns	Replacement of core explanatory variables	Replacement of estimation methods		Removal of outliers
	(1) 2SLS	(2) Entropy method	(3) GMM	(4) 2SLS	(5) Shrink tail
dige	0.149^{**}	0.151^{***}	0.026^{***}	0.061^{***}	0.123^{***}
	(2.282)	(4.640)	(2.868)	(7.146)	(8.508)
L.ic			0.578***		
			(8.302)		
pgdp	0.054	0.046	0.032	0.003	0.049^{*}
	(1.613)	(1.653)	(0.611)	(0.630)	(1.776)
foin	-0.025^{***}	-0.136^{***}	-0.149^{**}	-0.118^{***}	-0.121^{***}
	(−2.683)	(−7.208)	(−2.282)	(−7.511)	(−5.810)
asset	0.109^{***}	0.119^{***}	0.237^{***}	0.152^{***}	0.153^{***}
	(6.917)	(5.458)	(3.072)	(4.643)	(4.711)
indu	−0.034	0.183^{**}	0.049^{*}	0.046^{*}	-0.025^{***}
	(−1.620)	(2.044)	(1.840)	(1.661)	(−2.760)
wage	-0.127^{***}	-0.116^{***}	-0.112^{***}	0.186^{**}	-0.171^{*}
	(−5.817)	(−8.338)	(−7.423)	(2.025)	(−1.906)
Constant	-0.396^{***}	-0.489^{***}	-0.333^{***}	-0.226^{***}	-0.478^{***}
	(−6.840)	(−12.737)	(−5.724)	(−2.773)	(−12.373)
Observations	136	136	136	136	136
R-squared	0.932	0.931		0.924	0.928
City FE	yes	yes	no	yes	yes
Year FE	yes	yes	no	yes	yes
LM Statistics	32.462^{***}			17.508^{***}	
Wald F Statistics	594.662			506.452	
AR (1)			0.016		
AR (2)			0.684		
Hansen			0.846		

Note: *, **, and ***respectively represent significance at the significance level of 10%, 5%, and 1%, with the t-statistic of the estimate in parentheses. The same applies hereinafter.

Table A4. Heterogeneity test.

Variable	Economic development level heterogeneity		Urban locationl index heterogeneity		Marketization total index heterogeneity	
	Developed areas	Under development areas	heartland	Surrounding region	Higher area	Lower area
	(1)	(2)	(3)	(4)	(5)	(6)
dige	0.091**	0.051	0.163***	0.084**	0.011**	0.007
	(2.10)	(1.36)	(3.38)	(2.15)	(2.441)	(1.323)
pgdp	0.114***	0.437***	0.133**	0.292***	0.000***	0.000***
	(2.91)	(6.05)	(2.23)	(3.16)	(5.067)	(3.218)
foin	−0.009	−0.129***	−0.010	−0.004	−0.000***	−0.000***
	(−1.13)	(−2.76)	(−0.97)	(−0.05)	(−3.107)	(−2.902)
asset	0.014	−0.089***	−0.004	−0.207***	0.000	0.002**
	(0.56)	(−4.17)	(−0.18)	(−6.11)	(0.434)	(1.989)
indu	−0.153***	−0.009	−0.245***	−0.020	−0.000***	−0.062***
	(−5.97)	(−0.34)	(−5.39)	(−0.69)	(−9.121)	(−5.692)
wage	−0.086	−0.077	0.096	−0.128	−0.020*	−2.173
	(−1.22)	(−0.86)	(1.60)	(−1.24)	(−1.962)	(−1.194)
Constant	0.067	−0.697***	0.210**	−0.711***	0.011**	0.287***
	(0.63)	(−5.20)	(2.34)	(−3.64)	(2.441)	(18.691)
Observations	72	64	56	80	72	64
R-squared	0.946	0.848	0.919	0.972	0.879	0.862
City FE	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes