Digital economy, scientific and technological innovation, and high-quality economic development: A mediating effect model based on the spatial perspective

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Abstract

Although the effect of the digital economy in promoting high-quality economic development is increasing day by day, research analysing this mechanism from the spatial perspective is very scarce. This study measures the level of the digital economy and high-quality economic development based on the panel data of 31 provinces in China from 2013 to 2020. On this basis, the direct, spillover, and mediating effects of the digital economy and scientific and technological innovation on high-quality economic development are further analysed through the spatial Durbin model and mediating effect model. The main conclusions are as follows: (1) the digital economy, scientific and technological innovation, and high-quality economic development all show significant spatial correlation; (2) the digital economy can directly drive high-quality economic development, the spillover effect of which is obvious; and (3) the mechanism analysis based on the spatial perspective shows that the mediating effect of scientific and technological innovation is significant. The conclusions still hold after robustness tests based on the use of lagged variables, replacement of the weight matrices, and changing of the measurement methods. This study provides theoretical support and empirical evidence for promoting the digital economy and high-quality economic development.

1. Introduction

In the context of the transformation of old kinetic energy into new energy, a digital economy system with advanced technology, a strong driving force, rapid development, and extensive radiation is gradually taking shape [1]. The breadth and depth of the integration of the digital economy into social and economic development continue to expand. New products, services, models, and business formats have become the main engines for economic growth [2, 3]. According to data from the China Academy of Information and Communications Technology (CAICT) [4], during the second decade of the 21st century, the scale of the digital economy increased from 12.71 trillion yuan in 2013 to 39.20 trillion yuan in 2020, which is considered
an enormous increase (see Fig 1). This growth rate far exceeds that of gross domestic product (GDP), which is a major factor in the sustainment of economic growth (see Fig 1). The proportion of the scale of the digital economy in GDP has increased over time, accounting for nearly 40% in 2020, and has a trend of continuing to rise (see Fig 2). Moreover, the digital economy has a powerful driving effect on economic development. Therefore, the acceleration of the construction of the digital economy and boosting of high-quality economic development have become social propositions that governments and social sectors have paid close attention to in recent years [1].

Since Don Tapscott first proposed the term “digital economy” [5], research on the digital economy has spread worldwide. However, scholars and research institutions have not yet

Fig 1. Scale of the digital economy and its changes in China.
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Fig 2. Proportion of the digital economy scale in GDP and its changes in China.
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reached a consensus on the concept. The CAICT defines the concept of the digital economy in an accurate manner, which has been widely accepted by scholars, as a hybrid economy that uses data as a new type of production factor, takes well-developed networks, exerts the driving force of digital technology, and makes extensive use of digital knowledge to promote economic development [4].

In previous studies, a certain amount of literature has been accumulated from which we can obtain some useful conclusions. First, the digital economy has a direct effect on the promotion of high-quality economic development [1], and a spillover effect exists [6]. Second, scientific and technological innovation (STI) plays a mediating role in the relationship between the digital economy and high-quality economic development [7]. However, there is still room for improvement in previous studies, which also provides the opportunity for this study to make marginal contributions in this area. (1) Regarding the measurement of indicators, some scholars take a very simple approach; for example, for the measurement of high-quality economic development, only total factor productivity (TFP) is used [8, 9], causing this approach to lack a comprehensive consideration. In this study, we abandon the practice of a single indicator and measure the indicators of three variables from multiple perspectives, which is a more comprehensive approach to the examination of the indicators. (2) For the investigation of the mediating effect of STI, most previous scholars have based their studies on the ordinary least squares (OLS) model [7] and have not spatially explored the mediating effect. Thus, it is doubtful that this mediating effect of STI still exists in space. This study discusses this mechanism of the mediating effect by constructing a spatial Durbin model (SDM), the findings of which are more comprehensive and accurate, which is an enrichment and expansion of previous studies.

Therefore, this paper selects a total of 35 relevant data indicators for 31 provinces in China (excluding Hong Kong, Macau and Taiwan) from 2013 to 2020 and uses a double fixed effects SDM to analyse the role of the digital economy in high-quality economic development. Furthermore, from the spatial perspective, we examine the mechanism of the mediating effect and clarify the path of the effect of the digital economy in driving high-quality economic development by improving STI.

The remainder of this paper is organized as follows. Section 2 describes the theoretical analysis and research hypotheses, theoretically analysing the functional relationship between research objects. Section 3 presents the research design, including the setting of the empirical models, indicators and data sources. Section 4 presents the empirical analysis, including the spatial correlation analysis, spatial econometric regression analysis, mediating effect, and model robustness test. Finally, conclusions and policy recommendations are presented in Section 5.

2. Literature review and research hypotheses

2.1. Direct and spillover effects of the digital economy

Compared with traditional extensive growth, the digital economy promotes intensive development, which can directly drive high-quality economic development based on efficiency change, power change, and quality change. (1) In terms of efficiency change, the digital economy can promote the rational allocation of production factors, reduce production costs, and improve TFP [10, 11]. In the production process, the use of digital technologies, such as data collection, visualization, and the real-time monitoring of inputs and outputs, enterprises can continuously optimize production processes, rationally allocate production factors, approach the optimal production scale, and improve TFP [12]. (2) In terms of power change, the supply system of production factors has changed due to the digital economy. As a key production factor in the era of the digital economy, data are characterized by this "new economy", which
entails limited competitiveness, limited exclusivity, easy replication, externality, economies of scale, and economies of scope [13, 14]. Data factors effectively break the scarcity constraints of traditional factors (such as capital and labour) and maintain sustainable economic growth [15]. (3) In terms of quality change, the digital economy, through transformation and upgrading, promotes economic development. The wide application and penetration of digitalization subvert the mode of the industrial chain; dissolve the communication barriers between departments; virtualize the organizational boundary of enterprises [16, 17]; and promote the interconnection of upstream, midstream, and downstream enterprises in the industrial chain. At the same time, the digital economy can reduce the information asymmetry that exists in the product market and promote the reform of enterprises from batch supply to on-demand production. In particular, the emergence of digital platforms has realized the low-cost interconnection between enterprises and external subjects, strengthened the rapid response of enterprises to external consumption demand, and caused supply and demand to tend to achieve balance [18]. The digital economy reshapes the production mode, exchange mode, business mode, and value creation process of traditional industries, and improves the quality of economic development [19].

Economic activities in geographical space are not isolated [20], and spillover effects widely exist in economic phenomena [21]. The digital economy has a spillover effect because of its two important main effects. (1) Digital technology itself has the characteristics of positive spillover [22, 23]. With the help of digital technologies such as the internet and big data, data information can be stored and transmitted conveniently, compressing the space-time distance [24]. The cost of communication and exchange between subjects has been greatly reduced, and long-distance information transmission and real-time picture transmission have become the main content of information transmission, enhancing the capacity for such transmission. With the increase in the number of users, the marginal value of digital technology has not decreased but, rather, has increased. This kind of value produces a spillover effect with the development of the network [25]. (2) The spillover effect of economic activities is strengthened by the digital economy [20]. Economic activities among regions have significant spatial correlation, and scholars have confirmed the existence of a spillover effect [9]. The digital economy has promoted the communication and exchange of information, the flow of labour and capital factors, the efficiency of resource allocation, and spillover effects between regions [24].

Based on the above analysis, this study proposes the following hypothesis:

Hypothesis 1: The digital economy can promote high-quality economic development directly and have a spillover effect.

2.2. Mediating effect of STI

The digital economy promotes STI, which in turn promotes high-quality economic development. On the one hand, the digital economy provides the necessary foundation for the diversification of innovation subjects and modes, thus promoting STI development and progress [6]. (1) The digital economy provides the necessary conditions for the diversification of innovation subjects. For a long time, most of the innovation subjects discussed by scholars referred to enterprises. With the evolution of technological paradigms in the digital economy era, innovation subjects have expanded from enterprises to governments, universities, scientific research institutions, and even individuals. For example, the government participates in the process and results of innovation through subsidies [26]. With the help of digital technology, the information resources on which innovation relies are rapidly disseminated and widely spread, which causes the number of subjects who have access to innovation information to rapidly increase, and all kinds of subjects can participate in the innovation process, thus realizing the
diversification of innovation subjects [18]. (2) The digital economy transforms the innovation process from closed to open, and the participation of diversified innovation subjects requires a variety of innovative models to adapt to it. The digital economy enables the above needs to be realized at a low cost [9]. In the era of the digital economy, the subject of innovation is no longer limited to enterprises, and the innovation process is no longer a closed process within enterprises. The wide application of the digital economy has realized the cross-regional and cross-domain flow of data and information, and collaborative innovation has become the mainstream mode of innovation. Diversified innovation subjects and models have evolved into a rapidly changing innovation ecosystem [24].

On the other hand, STI can remove the constraints of the technological gap in development. Moreover, STI can also give birth to and evolve new economic forms and promote high-quality economic development. (1) The technological breakthroughs brought about by STI can eliminate the constraints of the technology gap in terms of development [27]. International experience shows that compared with developed countries in the high-end fields of international division in the industrial chain (the United States, Japan, Germany, etc.), China’s lack of high-tech and core technology accumulation has constrained its development. However, STI holds the promise of solving this dilemma in China [28]. (2) The achievements of STI can be transformed into real productivity, promote industrial structure upgrading and give rise to new business models, which in turn promote economic development. STI has led to the emergence of new energy and new technology enterprises and the flourishing of green industries with low pollution. Additionally, the proportion of emerging industries is increasing [29]. Moreover, the cross-application of STI in various fields has accelerated the formation of modern industrial systems, generating new industries such as e-commerce, the sharing economy, and big data; driving the emergence and development of intelligent industrial chains such as blockchain, driverless cars, and automation; and promoting high-quality economic development [19].

Based on the above analysis, the following hypothesis is proposed based on hypothesis 1:

Hypothesis 2: The mediating effect of STI exists, and this mediating effect also exists in space.

3. Research methods and data sources

3.1. Empirical model setting

Based on the theoretical analysis in the literature review section, this study sets up the corresponding models to analyse and verify the research hypotheses, and the research content and methods are shown in Fig 3.

3.2. Setting of the spatial correlation test

Spatial correlation is the premise and basis of spatial econometric analysis. Before analysing the spillover effect, a spatial correlation test should be carried out [30]. Moran’s I is used to test
the spatial correlation, which can be expressed as follows:

\[
\text{Moran’s I} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(Y_i - \bar{Y})(Y_j - \bar{Y})}{S^2 \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}}
\]  

(1)

where \(S^2\) represents the sample variance; \(Y\) represents the observed values; \(\bar{Y}\) represents the sample average value; \(i\) and \(j\) represent regions; \(n\) represents the number of regions, which is 31 in this study; and \(W_{ij}\) is the inverse distance weighted (IDW) matrix, which highlights the influence of adjacent areas and is characterized by having a greater impact on the local area than on distant areas [31]. Based on the significance of Moran’s I, the positive or negative direction and size of the value, spatial correlation can be judged.

### 3.3. Setting of the spatial econometric model

Mainstream econometric theory assumes that phenomena are irrelevant and homogeneous, ignoring the existence of spatial correlation and resulting in unreliable research results and inferences. The spatial econometric model considers the complex structural problems of spatial correlation and dependence [32], and in doing so, it is more in line with reality. The SDM is a combined extended form of the spatial error model (SEM) and the spatial lag model (SLM). In comparison, the use of the SDM can effectively reduce the problem of variable omission [30].

In this study, the SDM is selected for econometric analysis and is set as follows:

\[
\text{HD}_i = \beta_0 + \rho \sum_j w_{ij} \text{HD}_j + \beta_1 \text{DE}_i + \delta_1 \sum_j w_{ij} \text{DE}_j + \beta_2 Z_i + \delta_2 \sum_j w_{ij} Z_j + \mu_i + \gamma_t + \epsilon_{it}
\]  

(2)

In the above formula, \(t\) represents the year; \(HD\) represents the high-quality economic development level; \(DE\) represents the digital economy level; \(Z\) represents the control variables of the model; \(\mu\) and \(\gamma\) represent individual and time fixed effects, respectively; and \(\epsilon\) represents the random disturbance term.

### 3.4. Setting of the mediating effect test

Can the digital economy enhance high-quality economic development by improving STI? Is STI the mediator of this action path? To verify the above issues, referring to the research conclusions of Baron and Kenny [33] and Wen [34], the stepwise causality method is used from the spatial perspective based on SDM regression. The specific model settings are as follows:

\[
\text{Inn}_i = \theta_0 + \rho \sum_j w_{ij} \text{Inn}_j + \theta_1 \text{DE}_i + \phi_1 \sum_j w_{ij} \text{DE}_j + \theta_2 Z_i + \phi_2 \sum_j w_{ij} Z_j + \mu_i + \gamma_t + \epsilon_{it}
\]  

(3)

\[
\text{HD}_i = \beta_0 + \rho \sum_j w_{ij} \text{HD}_j + \beta_1 \text{DE}_i + \delta_1 \sum_j w_{ij} \text{DE}_j + \beta_2 \text{Inn}_i + \delta_2 \sum_j w_{ij} \text{Inn}_j + \beta_3 Z_i + \delta_3 \sum_j w_{ij} Z_j + \mu_i + \gamma_t + \epsilon_{it}
\]  

(4)

Among them, \(\text{Inn}\) represents the level of STI, and the definitions of the other variables and symbols are the same as those in Eq (2).

Referring to Fig 4, the steps for testing the mediating effect are as follows. The first step is to test whether total effect \(C\) exists (shown in Fig 4(B)), that is, whether the coefficient in Eq (2) is significant. If it is significant, then the test is continued, and otherwise, the test is terminated.
The second step is to test whether paths A and B exist (shown in Fig 4(A)), that is, whether the coefficients in Eqs (3) and (4) are significant. If both of them are significant, then the mediating effect exists. If at least one of them is not significant, then the existence is judged based on the Sobel test. The third step is to test whether a direct effect C' exists (shown in Fig 4(A)), that is, whether the coefficient in Eq (4) is significant. If it is significant, then the test result is a partial mediating effect. If not, then the test result is a full mediating effect.

3.5. Setting of the indicators

3.5.1. Setting of high-quality economic development. For high-quality economic development, there are two main measurement methods. The first is a single-indicator measurement method, using mainly TFP [8, 9], and the second method is a composite-indicator measurement method, establishing mainly an indicator system. Considering that high-quality economic development involves people's livelihood, society, the economy, and many other aspects, the single-indicator method is only a measurement of a certain angle or aspect and cannot fully reflect the high-quality economic situation. This study chooses the composite indicator method to build a measurement system covering 13 secondary indicators from three aspects—economic openness, social development, and ecological protection—as shown in Table 1.

In the selection of specific indicators, FDI and import and export amounts reflect the degree of economic openness. Highway mileage and the number of public toilets reflect the infrastructure situation. The teacher-to-student ratio and library data reflect the education situation [35]. Urban and rural incomes reflect the income level. Infrastructure, education, and income level are the basic aspects of social development [36]. The forest coverage rate and urban green coverage rate reflect the environmental conditions. The use of pesticides and the emission of sulphur dioxide and solid wastes reflect the environmental pollution caused by human activities. Environmental conditions and pollution conditions are important references for ecological protection [35].

The measurement system covers 13 secondary indicators. To simplify the calculation and analysis, it is necessary to reduce the dimensions of the indicators. Therefore, the entropy
weight method is used to obtain the weight of each indicator [37]. The comprehensive score, calculated based on weight, is used as the basis for measuring the high-quality economic development level.

3.5.2. Setting of the digital economy

Scholars mostly use composite indicators to measure the digital economy from different aspects. The measurement system in this study involves two parts—foundation and application—covering 11 secondary indicators, as shown in Table 2.

In terms of the foundation, the mobile phone penetration rate and digital inclusive financial index reflect the software infrastructure [19], the number of IT service staff and students in colleges reflect the human infrastructure [38], and the number of internet broadband access ports reflect the hardware infrastructure. In terms of the application, the value added of the secondary and tertiary industries reflects the overall application of the industry, the number of expressions reflects the application of the circulation industry, and the remaining indicators

**Table 1. Measurement system for high-quality economic development.**

| System                        | Primary index      | Secondary index                  | Unit            | Effect |
|-------------------------------|--------------------|-----------------------------------|-----------------|--------|
| High-quality economic develop | Economic openness  | Actual amount of FDI              | US$ 100 million | +      |
|                               |                    | Import and export amounts         | US$ 100 million | +      |
| Social development            | Mileage of major highways | 10 thousand km                    | +               |
|                               | Public toilets per 10 thousand people | seats                   | +               |
|                               | Student-to-teacher ratio in colleges | none                   | -               |
|                               | Ownership of public library books | volumes per person           | +               |
|                               | Disposable income of urban households | yuan per person          | +               |
|                               | Disposable income of rural households | yuan per person          | +               |
| Ecological protection         | Forest coverage    | %                                 | +               |
|                               | Pesticide usage    | ton                               | -               |
|                               | Green coverage rate of urban built-up areas | %                     | +               |
|                               | Sulphur dioxide emissions | 10 kilotons                | -               |
|                               | Output of general industrial solid waste | 10 kilotons              | -               |

Note: “Effect” indicates whether the indicator is positive (+) or negative (-). A positive (negative) effect indicates that the larger the value of the indicator is, the better (worse), and the same holds true below.

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weight method is used to obtain the weight of each indicator [37]. The comprehensive score, calculated based on weight, is used as the basis for measuring the high-quality economic development level.

**Table 2. Measurement system for the digital economy.**

| System       | Primary index               | Secondary index                      | Unit            | Effect |
|--------------|-----------------------------|--------------------------------------|-----------------|--------|
| Digital economy | Foundation              | Mobile phone penetration rate        | per 100 people | +      |
|               |                            | Number of staff in the IT service    | 10 thousand people | +      |
|               |                            | Number of students in colleges       | 10 thousand people | +      |
|               |                            | Digital inclusive financial index    | none            | +      |
|               |                            | Internet broadband access ports      | 10 thousand     | +      |
| Application  | Value added of the secondary industry | 100 million yuan | +               |
|               | Value added of the tertiary industry | 100 million yuan | +               |
|               | Total retail sales of social consumer goods | 100 million yuan | +               |
|               | Express                     | 10 thousand pieces                   | +               |
|               | Residents’ expenditure on transportation and communication | yuan per person | +               |
|               | Residents’ expenditure on education, culture, and entertainment | yuan per person | +               |

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reflect the application of the digital economy in various consumption fields [6]. As mentioned above, to facilitate calculation and analysis, the entropy weight method is used to reduce the dimension.

3.5.3. Setting of STI. STI is not only the achievement and application of the digital economy but also the driving force and source of high-quality economic development [29, 39]. Based on previous research results, this study selects representative indicators and constructs a measurement system covering 7 secondary indicators, as shown in Table 3.

In terms of the STI environment, the three indicators focus on reflecting the economic level of a region and the effect of the expenditure of public finance on cultivating an STI environment [29, 36]. In terms of STI investment, enterprises are the main body. The two selected indicators reflect mainly the funds and personnel that enterprises invest in STI [35]. In terms of STI output, the two selected indicators reflect mainly the achievements of STI and their transformation into practical applications. As above, the entropy weight method is used to reduce the dimension [39].

3.5.4. Setting of the control variables. The level of development varies greatly among Chinese provinces. To compare the rationality of the results, the impact of some factors needs to be controlled. Based on previous research [9, 35], this study selects four social indicators representing labour supply, public services, government intervention, and the urbanization level as control variables, as shown in Table 4.

As an important production factors, the labour factor influences the production of enterprises and economic development. The number of urban employees reflects the level of labour supply. The public service level represents the basis for social development, which is reflected by medical and health conditions [35]. The level of local government intervention affects marketization and represents a concern for development, which is reflected by local budget expenditures. As the carrier of internet development, cities affect popularization and development and are also an important aspect of shared development. The urbanization level is reflected by the proportion of the urban population among the total population [9].

3.6. Research samples and data sources

The research object includes 31 provinces in China, and 2013–2022 statistical panel data covering the 35 indicators are collected. The data used in the research are extracted mainly from the

### Table 3. Measurement system for STI.

| System          | Primary index       | Secondary index                                                                 | Unit           | Effect |
|-----------------|---------------------|---------------------------------------------------------------------------------|----------------|--------|
| STI             | STI environment     | GDP                                                                              | yuan per person| +      |
|                 |                     | Proportion of public financial expenditure on science and technology            | none            | +      |
|                 |                     | Proportion of public financial expenditure on education                         | none            | +      |
| STI input       | R&D expenditure of industrial enterprises above a designated size           | 10 thousand yuan                                                              | +              |
|                 | Full-time equivalent R&D personnel in industrial enterprises above a designated size | person-years   | +      |
| STI output      | Sales revenue from new products of industrial enterprises above a designated size | 10 thousand yuan                | +              |
|                 | Number of the three types of domestic patents granted                    | PCs                                               | +              |

### Table 4. Indicator system for control variables.

| System                  | Primary index     | Secondary index                                           | Unit           | Effect |
|-------------------------|-------------------|------------------------------------------------------------|----------------|--------|
| Control variables       | Labour supply     | Urban employed persons                                     | 10 thousand persons | +      |
|                         | Public services   | Number of beds in medical and health institutions          | pieces         | +      |
|                         | Intervention intensity of local governments | Local budget expenditure                                   | 100 million yuan  | +      |
|                         | Urbanization level | Proportion of the urban population                          | none           | +      |
4. Empirical analysis

4.1. Spatial correlation analysis

The results of Moran’s I are shown in Table 6. These results show that the development in each region is not independent of each other but has an obvious positive spatial correlation. Further analysis reveals that Moran’s I values of the digital economy and STI fluctuate slightly upwards and downwards within a certain range during this period, indicating that the spatial correlation between the digital economy and STI varies among regions but is relatively stable. Moran’s I value of the high-quality economic development level shows a fluctuating upwards trend, with the peak appearing in 2020. These results show that the spatial correlation among regions is gradually increasing. The conclusions of the test based on Moran’s I show that the variables in the model have spatial correlation; thus, a spatial econometric model with spatial effects should be used.

4.2. Spatial econometric regression analysis

4.2.1. Analysis of the SDM. After determining the use of a spatial econometric model, the specific form of the model should be further determined. Based on panel data, the statistics of the Hausman test [40] obey the rule of a $\chi^2$ distribution with 6 degrees of freedom; the test value is 39.77 (p value < 0.01). The original random effects hypothesis is strongly rejected, and the fixed effects model is selected.

Table 6. Global Moran’s I values.

| Year | Digital economy | p value | Moran’s I | p value | STI | p value | Moran’s I | p value | High-quality economic development | p value |
|------|-----------------|---------|-----------|---------|------|---------|-----------|---------|-----------------------------------|---------|
| 2013 | 0.177           | 0.000   | 0.187     | 0.000   |     |         |           |         | 0.171                             | 0.000   |
| 2014 | 0.172           | 0.000   | 0.196     | 0.000   |     |         |           |         | 0.181                             | 0.000   |
| 2015 | 0.173           | 0.000   | 0.182     | 0.000   |     |         |           |         | 0.166                             | 0.001   |
| 2016 | 0.170           | 0.000   | 0.187     | 0.000   |     |         |           |         | 0.185                             | 0.000   |
| 2017 | 0.165           | 0.000   | 0.177     | 0.000   |     |         |           |         | 0.162                             | 0.001   |
| 2018 | 0.167           | 0.000   | 0.176     | 0.000   |     |         |           |         | 0.183                             | 0.000   |
| 2019 | 0.172           | 0.000   | 0.179     | 0.000   |     |         |           |         | 0.198                             | 0.000   |
| 2020 | 0.164           | 0.000   | 0.183     | 0.000   |     |         |           |         | 0.202                             | 0.000   |

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a fixed effects model should be selected. Furthermore, the likelihood ratio (LR) statistic is 59.38 (p value < 0.01). The original hypothesis is rejected, and a double fixed effects model with individual and time points should be selected. Therefore, the final analysis model of this study is the double fixed effects SDM. Stata 15.1 and maximum likelihood estimation (MLE) are used to estimate Eq (2), and the model estimation results are shown in Table 7. Furthermore, the logarithms of the variables are used to weaken the influence of heteroscedasticity.

As shown in Table 7, both in models 1 and 2, the coefficients of variables lnDE and W.lnDE are significantly positive (p value < 0.01), indicating that improving the digital economy in adjacent areas can indeed promote an improvement in the economic development of the local region. These results are the same as the findings of Liang et al. [38]. The coefficient of lnEmp is positive, but that of W.lnEmp is negative, although they are both significant. This finding indicates that an increase in urban employment in a region, that is, an increase in labour supply, can promote economic development but can also have a dampening effect on the development of adjacent areas. The reason for this may be that the labour factor is a highly mobile factor of production and that increasing the labour supply level in the region attracts the inflow of the labour factor from adjacent areas. Therefore, this situation leads to the loss of labour factors from adjacent areas [41]. The coefficients of the variables representing the level of public services, government intervention, and urbanization are significant, but those with the spatial weight matrix terms are not significant. These results indicate that these three variables produce a noticeable impact on the local region, but the impact on adjacent areas remains unclear. The reason for this may be that the

### Table 7. Regression results of the SDM.

| Variables | Model 1 (W1) | Model 2 (W2) |
|-----------|--------------|--------------|
|           | Coefficient  | t-statistic  | Coefficient  | t-statistic  |
| lnDE      | 0.224***     | 3.71         | 0.171***     | 2.67         |
| lnEmp     | 0.217**      | 2.27         | 0.249***     | 2.68         |
| lnMed     | 0.264'       | 1.71         | 0.218        | 1.48         |
| lnFis     | 0.222**      | 2.34         | 0.288***     | 3.48         |
| lnPop     | 0.381'       | 1.90         | 0.390'       | 1.90         |
| W.lnDE    | 2.766***     | 4.83         | 0.698***     | 3.34         |
| W.lnEmp   | -2.231***    | -3.06        | -0.562'      | -1.88        |
| W.lnMed   | 0.903        | 0.97         | 0.671        | 1.54         |
| W.lnFis   | -0.251       | -0.35        | 0.387        | 1.46         |
| W.lnPop   | -1.34        | -1.11        | -1.314''     | -2.06        |
| Spatial-rho | -0.496'     | -1.67        | -0.131       | -0.89        |
| Sigma2_e  | 0.004***     | 11.07        | 0.004***     | 11.12        |

| Individual fixed effect | Yes | Yes |
| Time fixed effect       | Yes | Yes |
| Number of regions       | 31  | 31  |
| N                       | 248 | 248 |

Note:
*p < 0.10
**p < 0.05, and
***p < 0.01; the same holds true below.

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mobility of these three variables is poor, and thus, they can have a significant impact only on the local region.

4.2.2. Analysis of direct, indirect and total effects. For the spatial spillover effect, the point estimation method of one or more spatial econometric models is flawed [30], and thus, it is more appropriate to conduct an analysis from the perspective of the indirect effect. The direct effect, specifically, refers to the influence between variables in the local region. There are two action paths: first, local independent variables affect local dependent variables, which is numerically equal to the SDM coefficient, and second, local independent variables affect adjacent dependent variables, which in turn affect local dependent variables. This effect is called the feedback effect. The direct effect, numerically, is equal to the sum of the model coefficient and the feedback effect. The indirect (spillover) effect refers to the influence between variables among regions. The total effect, numerically, is the sum of direct and indirect effects.

Based on Eq (2), the IDW matrix is used to estimate the three types of variable effects. The estimation results are shown in model 1 in Table 8.

On the impact of direct effects, the coefficient of lnDE is significantly positive, which shows that the direct effect of the digital economy exists. This finding is consistent with those of Cai and Ma [14]. Moreover, the coefficients of labour supply, public services, government intervention, and urbanization level are significantly positive. The labour factor is an important factor of production, the level of public services represents a soft condition to ensure economic development [35], the level of government intervention is a direct manifestation of the government’s concern and promotion of economic development, and urbanization affects the popularity and application of network infrastructure [9]. Therefore, the improvement of all the above factors makes a direct contribution to economic development.

On the impact of indirect effects, the coefficient of lnDE is significantly positive, which shows that the indirect effect of the digital economy exists. This finding is consistent with those of Lu et al. [19]. The coefficient of urban employed persons, at the 5% level, is significantly negative, which indicates that improving the labour supply in the local region inhibits the economic development of adjacent areas, which is consistent with the previous findings for W.InEmp. The coefficients of public services, government intervention, and urbanization level are not significant, indicating that these variables have nonsignificant effects on adjacent areas.

Table 8. Regression results of direct, indirect and total effects.

| Variables | Direct | Indirect | Total | Model 1 | Direct | Indirect | Total | Model 3 | Direct | Indirect | Total | Model 4 | Direct | Indirect | Total |
|-----------|--------|----------|-------|---------|--------|----------|-------|---------|--------|----------|-------|---------|--------|----------|-------|
| lnDE      | 0.176*** | 1.868*** | 2.043*** | 0.238** | 2.333*** | 2.571*** | 0.130* | 1.302*** | 1.432*** |         |       |         |        |          |       |
|           | (2.60)  | (3.64)   | (3.92) | (2.27)  | (3.02)  | (3.29)   | (1.98) | (3.05)  | (3.36) |         |       |         |        |          |       |
| lnInn     | 0.108*** |         |       | 0.272   | 0.381   |         |       | 0.181*  |         |         |       |         |        |          |       |
|           | (2.77)  | (1.36)   | (1.89) | (0.72)  | (1.53)  |         |       | (1.86)  | (2.88)  |         |       |         |        |          |       |
| lnEmp     | 0.256*** | -1.694** | -1.438** | 0.748*** | 0.600   | 1.348   | 0.179* | -1.674*** | -1.495** |         |       |         |        |          |       |
|           | (2.77)  | (-2.48)  | (-2.01) | (5.29)  | (0.72)  | (1.53)  | (1.86) | (-2.88) | (-2.46) |         |       |         |        |          |       |
| lnMed     | 0.266*** | 0.496    | 0.762  | 0.083   | 1.716   | 1.799*  | 0.222 | 0.071   | 0.293  |         |       |         |        |          |       |
|           | (1.73)  | (0.76)   | (1.21) | (0.34)  | (1.58)  | (1.71)  | (1.44) | (0.11)  | (0.49) |         |       |         |        |          |       |
| lnFis     | 0.228*** | -0.216   | 0.012  | 0.093   | -0.667  | -0.574  | 0.225** | -0.203  | 0.022  |         |       |         |        |          |       |
|           | (2.62)  | (-0.43)  | (0.02) | (0.67)  | (-0.79) | (-0.64) | (2.67) | (-0.48) | (0.05) |         |       |         |        |          |       |
| lnPop     | 0.405**  | -1.012   | -0.607 | 1.976*** | -2.098  | -0.121  | 0.198  | -1.114  | -0.915 |         |       |         |        |          |       |
|           | (2.07)  | (-1.20)  | (-0.76) | (6.41)  | (-1.50) | (-0.09) | (0.89) | (-1.34) | (-1.19) |         |       |         |        |          |       |

Note: The values in brackets are t-statistics, and individual and year fixed effects are controlled but are not listed to save space; the same holds true below.

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Concerning the impact of total effects, the coefficient of lnDE is also significantly positive, which shows that an overall promotion effect exists. In addition, the existence of direct and spillover effects has been discussed in the previous section; therefore, hypothesis 1 is verified. The coefficient of urban employed persons, at the 5% level, is significantly negative. Based on the above analysis, the labour supply in the local region plays an important direct role in promoting the digital economy of the local region but hinders the development of adjacent regions. The coefficients of the number of beds in medical and health institutions, local financial budget expenditure, and the proportion of the urban population are not significant, and the impact is not obvious.

Overall, the three types of effects of the digital economy are significantly positive. Additionally, the indirect effect (model coefficient 1.868) is greater than the direct effect (model coefficient 0.176), indicating that the impact on adjacent regions is greater than that on the local region. The reason for this may be that this promoting effect depends mainly on the diffusion of the spillover effect, and the direct effect itself is weak. The digital and agglomeration characteristics make the cost of communication and diffusion low and the cost of self-generation high. Therefore, the spillover effect on adjacent areas becomes increasingly stronger. Therefore, improving the labour supply significantly promotes economic development in the local region but can also inhibit the development of adjacent areas, and the inhibiting effect is stronger. The remaining control variables have a significant direct effect, but the indirect and total effects are nonsignificant, and the impact effect is not clear.

4.3. Mediating effect analysis

From the spatial perspective, the verification and analysis of the mediating effect of STI are carried out.

As shown in Table 8, models 1, 3, and 4 are based on the double fixed effects SDM. The core explanatory variable of models 1 and 3 is the digital economy level, but the explained variables differ: the high-quality economic development and STI levels, respectively. The explained variable of model 4 is the same as that of model 1, which is the high-quality economic development level, but there are two core explanatory variables, i.e., the digital economy level and STI level, and the control variables of the three models are the same. The regression result of model 1 corresponds to Eq (2), that is, to test whether or not total effect path C, shown in Fig 4 (B), is significant. The regression result of model 3 corresponds to Eq (3), that is, to test whether or not path A, shown in Fig 4(A), is significant. The regression result of model 4 corresponds to Eq (4), that is, to test whether or not path B and direct effect path C’, shown in Fig 4(A), are significant.

The test steps and analysis results of the mediating effect are as follows. First, by using Eq (2) and obtaining model 1 in Table 8, the results show that total effect path C is significantly (p value < 0.01) positive. Then, using Eq (3) and obtaining model 3 in Table 8, the results show that path A is significantly (p value < 0.01) positive. In addition, by using Eq (4) and obtaining model 4 in Table 8, the results show that paths B and C’ are significantly positive, indicating that the level of STI has a partial mediating effect, the proportion of which is (2.571 * 0.381)/ 2.043 = 47.95%.

The analysis of mediating effects can lead to some meaningful conclusions. The digital economy can improve STI to directly drive high-quality economic development in the local region. These findings are in line with those of scholars who have used OLS estimation methods [7, 8]. Concurrently, the digital economy in the local region can also promote the high-quality economic development of adjacent regions by improving their STI, and a significant positive spillover effect exists. Therefore, hypothesis 2 is verified. The action path of hypothesis

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Overall, the three types of effects of the digital economy are significantly positive. Additionally, the indirect effect (model coefficient 1.868) is greater than the direct effect (model coefficient 0.176), indicating that the impact on adjacent regions is greater than that on the local region. The reason for this may be that this promoting effect depends mainly on the diffusion of the spillover effect, and the direct effect itself is weak. The digital and agglomeration characteristics make the cost of communication and diffusion low and the cost of self-generation high. Therefore, the spillover effect on adjacent areas becomes increasingly stronger. Therefore, improving the labour supply significantly promotes economic development in the local region but can also inhibit the development of adjacent areas, and the inhibiting effect is stronger. The remaining control variables have a significant direct effect, but the indirect and total effects are nonsignificant, and the impact effect is not clear.

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The analysis of mediating effects can lead to some meaningful conclusions. The digital economy can improve STI to directly drive high-quality economic development in the local region. These findings are in line with those of scholars who have used OLS estimation methods [7, 8]. Concurrently, the digital economy in the local region can also promote the high-quality economic development of adjacent regions by improving their STI, and a significant positive spillover effect exists. Therefore, hypothesis 2 is verified. The action path of hypothesis
2 is that the digital economy improves the STI level, which in turn promotes high-quality economic development in the same region, and the digital economy in the local region drives the high-quality economic development of adjacent regions through the spillover effect.

4.4. Robustness tests

The robustness of the model is tested by using the lag period of the explanatory variables [19, 29], replacing the spatial weight matrix [22], and changing the calculation method of the data [42]. Based on the test results in Table 9, the coefficients and significance level are shown to fluctuate slightly; however, the main conclusions of the model remain unchanged. That is, the results of the robustness tests indicate the relative stability of the empirical results.

According to the previous analysis, it is clear that both the digital economy and STI contribute to high-quality economic development. Moreover, regions with better economic development, which have better infrastructure and a more complete industrial structure, are more conducive to the enhancement of the digital economy and STI. To address the possible bias caused by mutual causality, the two variables of the digital economy and STI are treated with a one-period lag. The reasons for doing so are as follows. (1) The digital economy and STI in the lagged period are unrelated to those in the current period, and the economic level, thus, cannot have impact them. (2) The digital economy and STI represent development capabilities, and the contribution of such capabilities to economic development persists; thus, the digital economy and STI in the lagged period still have an impact on economic development. Therefore, the reciprocal causality problem can be solved by adopting a one-period lag approach [29].

The re-estimated results, shown in model 5 in Table 9, show that the three types of effects of the digital economy still hold. Additionally, the significance of the direct and indirect effects of STI remains unchanged, the conclusion of the analysis is highly consistent with the conclusion of model 4, and the results are robust.

In the SDM, the weight matrix reflects the spatial relationship between variables. In this study, the IDW matrix is mainly used. To test the robustness of the model, the IDW matrix is replaced with the adjacency weighted matrix. The re-estimation results, shown in model 6 in Table 9, are consistent with the results in model 4. There is no obvious change, and the regression results are robust.

In the model setting, the comprehensive score of the mediating variable STI is recalculated. The weighting method changes from the entropy weight method to the average weight method; that is, all indicators are treated with equal weight. The re-estimated results are shown in model 7 in Table 9. It is found that the values of the three effects of the digital economy increase, but their positive or negative direction and significance levels do not change and are highly significant. The value of the direct effect of STI decreases, and the significance level decreases, but it is still significant (p value < 0.1). The values of the three effects remain positive and unchanged. The conclusions of the analysis of the direct and indirect effects are consistent with those in model 4 and are unchanged. Furthermore, the results are robust.

| Variables | Model 5 | Model 6 | Model 7 |
|-----------|---------|---------|---------|
|           | Direct  | Indirect| Total   | Direct  | Indirect| Total   | Direct  | Indirect| Total   |
| lnDE      | 0.178** | 0.780*  | 0.958** | 0.152** | 0.486** | 0.637***| 0.162** | 1.558***| 1.720***|
|           | (2.20)  | (1.87)  | (2.31)  | (2.35)  | (2.49)  | (3.04)  | (2.47)  | (3.39)  | (3.74)  |
| lnInn     | 0.129***| 0.177   | 0.306   | 0.094** | -0.007  | 0.086   | 0.063* | 0.167   | 0.230   |
|           | (2.79)  | (0.74)  | (1.25)  | (2.33)  | (-0.06) | (0.73)  | (1.83)  | (0.83)  | (1.14)  |

Controls  Yes Yes Yes

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5. Conclusions and policy recommendations

Using the panel data of 31 provinces from 2013 to 2020 in China, this study systematically demonstrates and analyses the direct, spillover, and mediating effects of the digital economy and STI in promoting high-quality economic development. The main conclusions are as follows. (1) Geographically and spatially, a significant spatial correlation among the digital economy, STI, and high-quality economic development exists, and the development of each region is interrelated. (2) The direct and spillover effects of the digital economy to promote high-quality economic development are obvious. (3) From the spatial perspective, the mediating effect of STI is significant, and according to the calculation results, the mediating effect accounts for approximately 47.95%.

The policy implications are as follows. (1) The direct and spillover effects of the digital economy should be released to promote development. In terms of direct effects, we should focus on the construction of both the foundation and application of such effects. To strengthen the construction of infrastructure, we should make efforts in terms of hardware and software. We should not only improve the coverage of mobile communication and networks in terms of hardware and accelerate the investment in the construction of 5G, AI, and other new infrastructure but also cultivate and introduce relevant talent in software and improve supporting financial auxiliary measures and the policy environment. To strengthen the practical application, we should broaden the application scope, strengthen the integration depth, and let the digital economy play a dual driving role in terms of boosting industrial upgrading and cultivating new growth points. In terms of spillover effects, considering that directly upgrading the digital economy requires higher costs and longer time cycles, a collaborative development network can be built by digital technology to introduce and develop industries, technologies, etc., to achieve cross-regional cooperation and narrow the regional development gap. (2) The mediating effect of STI should be released by improving the environment, increasing investment, and accelerating the transformation of results. The innovation environment is the foundation of STI. We should increase public expenditure on technology, science, and education and enhance the level of the innovation environment. Enterprises are the main body of STI, and innovation investment is a necessary condition for STI. Enterprises should be encouraged to increase their innovation investment and hire innovative talent. We should support enterprises in developing STIs, solving problems, and providing good services. Moreover, the output of STI is an important aspect of such application. We should enhance the incubation capacity of STI output, accelerate the transformation and implementation of STI achievements, realize the promotion and use of STI achievements quickly, and improve the level of development.

However, several limitations in this study may present directions for future research. (1) In terms of the research object, although the measurement of the digital economy has subdivision dimensions, due to the research content and length of the article, there is no discussion on these factors in this work. In future research, we can start from this perspective to analyse the heterogeneity of the impact of different subdivision dimensions. (2) In the treatment of mechanism variables, this work adopts a comprehensive indicator approach to measure STI. In future studies, the efficiency analysis of STI based on inputs and outputs can be considered for more in-depth exploration and research.

Supporting information

S1 Data.
(XLSX)
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References
1. Zhao T, Zhang Z, Liang SK. Digital economy, entrepreneurship, and high-quality economic development: empirical evidence from urban China. Management World. 2020; 36(10): 65–76. https://doi.org/10.19744/j.cnki.11-1235/f.2020.0154
2. Heo PS, Lee DH. Evolution of the linkage structure of ICT industry and its role in the economic system: the case of Korea. Information Technology for Development. 2019; 25(3): 424–454. https://doi.org/10.1080/02681102.2018.1470486
3. Lee S, Kim MS, Park Y. ICT Co-evolution and Korean ICT strategy: An analysis based on patent data. Telecommunications Policy, 2009; 33(5–6): 253–271. https://doi.org/10.1016/j.telpol.2009.02.004
4. White Paper on China’s Digital Economy Development. China Academy of Information and Communications Technology. 2021; 1–88. Available from: http://www.caict.ac.cn.
5. Tapscott D. The Digital Economy Anniversary Edition: Rethinking promise and peril in the age of networked intelligence. New York: McGraw Hill Professional; 2014.
6. Yang HM, Jiang L. Digital Economy, Spatial Effects and Total Factor Productivity. Statistical Research. 2021; 38(04): 3–15. https://doi.org/10.19343/j.cnki.11-1302/c.2021.04.001
7. Zhang LL, Pan A, Feng SS, Qin YY. Digital economy, technological progress, and city export trade. PloS one. 2022; 17(6): e0269314. https://doi.org/10.1371/journal.pone.0269314 PMID: 35657946
8. Zhang W, Zhao SQ, Wan XY, Yao Y. Study on the effect of digital economy on high-quality economic development in China. PloS one. 2021; 16(9): e0257365. https://doi.org/10.1371/journal.pone.0257365 PMID: 34547019
9. Xu XH. Digital Economy and High-quality Economic Development: An Empirical Study Based on the Upgrading of Industrial Structure. Statistics & Decision. 2022; 38(01): 95–99. https://doi.org/10.13546/j.cnki.12.2022.01.020
10. Cotte G, Neuvoux S, Py L. The impact of ICTs and digitalization on productivity and labor share: evidence from French firms. Economics of innovation and new technology. 2021; 1–24. https://doi.org/10.1080/10438599.2020.1849967
11. Cardona M, Kretschmer T, Strobel T. ICT and productivity: conclusions from the empirical literature. Information Economics and Policy. 2013; 25(3): 109–125. https://doi.org/10.1016/j.inforecopol.2012.12.002
12. Campos J, Sharma P, Gabiria UG, Jantunen E, Baglee D. A big data analytical architecture for the Asset Management. Procedia CIRP. 2017; 64: 369–374. https://doi.org/10.1016/j.procir.2017.03.019
13. Jones CJ, Tonetti C. Nonrivalry and the Economics of Data. American Economic Review. 2020; 110(9): 2819–58. https://doi.org/10.1257/ater.20191330
14. Cai YZ, Ma WJ. How Data Influence High-quality Development as a Factor and the Restriction of Data Flow. The Journal of Quantitative & Technical Economics. 2021; 38(03): 64–83. https://doi.org/10.13653/j.cnki.jqte.2021.03.002
15. Van Bart A. The productivity paradox of the new digital economy. International Productivity Monitor. 2016; (31): 3–18.
16. Ding XC, Liu XL. The Analytical Framework for Enterprise Innovation Management and Transformation in the Big Data Era. Science Research Management. 2018; 39(12): 1–9. https://doi.org/10.19571/j.cnki.1000-2995.2018.12.001
17. Boudreau MC, Loch KD, Robey D, Straud D. Going global: Using information technology to advance the competitiveness of the virtual transnational organization. Academy of Management Perspectives. 1998; 12(4): 120–128. https://doi.org/10.5465/ame.1998.1334008

18. Kang J, Chen KH. Digital Innovation Development Economic System: The Framework, Evolution and Value Creation Effect. Science Research Management. 2021; 42(04): 1–10. https://doi.org/10.19571/j.cnki.1000-2995.2021.04.001

19. Lu YX, Fang XM, Zhang AQ. Digital Economy, Spatial Spillover and High-Quality Development of Urban Economy. Economic Survey. 2021; 38(06): 21–31. https://doi.org/10.15931/j.cnki.1006-1096.2021.06.003

20. Tobler WR. A computer movie simulating urban growth in the Detroit region. Economic geography. 1970; 46(sup1): 234–240.

21. Zhang WK, Tian XL, Yu A. Is high-speed rail a catalyst for the fourth industrial revolution in China? Story of enhanced technology spillovers from venture capital. Technological Forecasting and Social Change. 2020; 161: 120286. https://doi.org/10.1016/j.techfore.2020.120286

22. Li SS, Zhang M. Big Data Industry, Regional Technological Innovation Efficiency and Financial Technology Development: An Empirical Analysis Based on Spatial Durbin Model and Mediating Effect. Financial Theory & Practice. 2021; (07): 10–18.

23. Anselin L, Varga A, Acs Z. Geographical spillovers and university research: A spatial econometric perspective. Growth and change. 2000; 31(4): 501–515. https://doi.org/10.1108/0017-4815.2000.00142

24. Bathelt H, Malmberg A, Maskell P. Clusters and knowledge: local buzz, global pipelines and the process of knowledge creation. Progress in Human Geography. 2004; 28(1): 31–56. https://doi.org/10.1191/0309132504ph469oa

25. Yilmaz S, Haynes KE, Dinc M. Geographic and network neighbors: Spillover effects of telecommunications infrastructure. Journal of Regional Science. 2002; 42(2): 339–360. https://doi.org/10.1111/j.1467-9787.00262

26. Liu SY, Du J, Zhang WK, Tian XL. Opening the box of subsidies: which is more effective for innovation?. Eurasian Business Review. 2021; 11(3): 421–449. https://doi.org/10.1007/s40821-020-00178-2

27. Grilliches Z. R&D and the Productivity Slowdown. The American Economic Review. 1980; 70(2): 343–348.

28. Gu SZ, Wu HJ, Wu QQ, Yu XW. Innovation-driven and Core Technology Breakthrough: The Cornerstone of High-quality Development. China Soft Science. 2018; (10): 9–18.

29. Li GL, Fan XX. Fiscal Expenditure, Scientific and Technological Innovation and High-Quality Economic Development: An Empirical Analysis Based on Spatial Durbin Model and Mediating Effect. Shanghai Journal of Economics. 2019; (10): 46–60. https://doi.org/10.19626/j.cnki.cn31-1163/f.2019.10.006

30. LeSage J, Pace RK. Introduction to spatial econometrics. New York: Chapman and Hall/CRC; 2009.

31. Getis A, Aldstadt J. Constructing the spatial weights matrix using a local statistic. Geographical analysis. 2004; 36(2): 90–104. https://doi.org/10.1111/j.1538-4632.2004.tb0127.x

32. Anselin L, Syabri I, Kho Y. GeoDa: An Introduction to Spatial Data Analysis. Handbook of applied spatial analysis. Springer-Verlag Berlin Heidelberg; 2010. pp. 73–89. https://doi.org/10.1007/978-3-642-03647-7_5

33. Baron RM, Kenny DA. The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. Journal of personality and social psychology. 1986; 51(6): 1173–82. https://doi.org/10.1037/0022-3514.51.6.1173 PMID: 3806354

34. Wen ZL, Zhang L, Hou JT, Liu HY. Testing and Application of the Mediating Effects. Acta Psychologica Sinica. 2004; (05): 614–620.

35. Wei M, Li SH. Study on the Measurement of Economic High-quality Development Level in China in the New Era. The Journal of Quantitative & Technical Economics. 2018; 35(11): 3–20. https://doi.org/10.13653/j.cnki.jqte.2018.11.001

36. Wang W. A Study on the Measurement and Evaluation of the High-quality Development of China’s Economy. East China Economic Management. 2020; 34(06): 1–9. https://doi.org/10.19629/j.cnki.34-1014/f.200216001

37. Lin J. Divergence measures based on the Shannon entropy. IEEE Transactions on Information Theory. 1991; 37(1): 145–151. https://doi.org/10.1109/18.61115

38. Liang Q, Xiao SP, Li MX. Digital Economy Development, Spatial Spillover and Innovation Quality Growth: The Threshold Effect Test of Market Efficiency. Shanghai Journal of Economics. 2021; (09): 44–56. https://doi.org/10.19626/j.cnki.cn31-1163/f.2021.09.004
39. Wang HY, Li XY, Xu YL. Research on Performance Evaluation and Influencing Factors of High-quality Economic Development Driven by Scientific and Technological Innovation in China. Economist. 2019; (11): 64–74. https://doi.org/10.16158/j.cnki.51-1312/f.2019.11.008

40. Hausman JA. Specification tests in econometrics. Econometrica: Journal of the econometric society. 1978; 46(6): 1251–1271. https://doi.org/10.2307/1913827

41. Wu T, Yi M. Talent's Resource Matching, Technical Efficiency and China's High-quality Economic Development. Studies in Science of Science. 2019; 37(11): 1955–1963. https://doi.org/10.16192/j.cnki.1003-2053.2019.11.005

42. Qi YD, Liu CH, Ding SL. Digital Economic Development, Employment Structure Optimization and Employment Quality Upgrading. Economic Perspectives. 2020; (11): 17–35.