

Evaluation of digital innovation in smart homes – based on bibliometrics and rooted theory

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Abstract

Purpose – To evaluate the level of digital innovation in the smart home industry.

Design/methodology/approach – By employing bibliometric analysis and grounded theory, this study aims to assess the innovation capabilities of leading manufacturing enterprises and establish a digital innovation evaluation system for smart homes.

Findings – Scientific arguments show that the cultivation of innovation capability should focus on three aspects of knowledge innovation, product innovation and technological innovation. Utilizing the four first-level indicators and 15 second-level indicators derived from the previous sections, we conducted TF-IDF (Term Frequency-Inverse Document Frequency) words frequency matching on the annual reports of A-share smart home listed companies. The resulting score for the company across these four primary indicators was then considered as the score for the digital innovation level indicator.

Originality/value – The evaluation system includes first-level indicators such as technological innovation, production innovation, management innovation and sales innovation and second-level indicators such as digital technology, intelligent manufacturing, industrial Internet, green intelligent manufacturing, flexible robot production and cross-border integration, which provides smart home enterprises with a reference to understand the level of digital innovation, improve the deficiencies and promote the development of the smart home industry.

Keywords Digital economy, Digital innovation, Manufacturing, Smart home

Paper type Research paper

1. Introduction

1.1 Background and significance of the study

As an emerging lifestyle, smart home technology enables comprehensive household management through advanced intelligent systems, delivering a seamless and sophisticated

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user experience Established household appliance manufacturers like Midea, Haier, and Gree have proactively adapted by leveraging their product portfolios and market presence to embrace smart homes. With the advent of the era of interconnectivity, there is robust momentum behind comprehensive smart living solutions, making digital innovation a key strategic priority for home furnishing enterprises. Not only does digital innovation enhance user experience through superior smart home offerings but it also bolsters enterprise competitiveness and market penetration. China's pursuit of a leading role in the global smart home market highlights the development of digital innovation is of great importance.

1.2 Purpose of the study and research questions

Evaluating the digital innovation level of smart home enterprises is a crucial area of interest for both industry and academia. Presently, the existing literature predominantly assesses enterprise digitalization from a one-dimensional standpoint. For instance, [Qi et al. \(2020\)](#) utilize the ratio of the amount of intangible assets related to the digital economy to the total amount of intangible assets to measure the degree of enterprise digitization, while multi-dimensional perspectives are mostly evident in research content innovation. There are fewer researches on multi-dimensional assessment of smart home industry digitalization.

The assessment of the smart home industry's capacity for digital innovation lacks a unified standard, as indicated by literature research. The current theoretical framework proposed by scholars emphasizes qualitative analysis and includes a limited number of indicators. Moreover, the index system established does not sufficiently address the assessment of digital innovation in the smart home industry. Furthermore, there are certain limitations in the explanatory variables used. For example, employing the fraction of total business intangible assets to measure digitization level raises issues related to rigor.

Based on theoretical research on the evaluation of enterprise innovation ability, this study employs grounded theory and bibliometrics to develop an actionable evaluation system for assessing innovation ability in the manufacturing sector. Through empirical research utilizing questionnaires and relevant specific data, it aims to identify the distinctive characteristics of enterprise thinking regarding the high level of digitalization in the smart home industry. Additionally, the study seeks to explore the driving forces behind the digitalization of innovation specifically within the smart home industry. The findings aim to provide insights, ideas, and methodologies for cultivating and enhancing innovation ability in the digital transformation of the smart home industry. The ultimate objective is to contribute to the development and advancement of the digitalization of innovation in the smart home industry.

Drawing from theoretical research on evaluating enterprise innovation capability, this study utilizes grounded theory and bibliometrics to construct a practical assessment framework for appraising innovative capacity within manufacturing. Employing empirical methods including questionnaires and targeted data analysis, it seeks to summarize the characteristics of advanced digital innovation in the smart home industry and explore the driving forces behind this innovation. Furthermore, this paper aims to offer insights and strategies for fostering and enhancing the digital innovation capabilities within the smart home industry.

2. Literature review

2.1 Status and significance of digital innovation

According to McKinsey study, just 20% of Chinese businesses have successfully made the transition to digital platforms, and the results haven't been great. This indicates that while digital innovation is recognized as crucial, its implementation is still a challenge for many enterprises. [Xie et al. \(2023\)](#) contend that enterprises exhibit excellent performance in the degree of investment and benefits of digital technology, suggesting that enterprises have

gradually acknowledged the significance and urgency of digitalization. Nevertheless, the considerable gap in digital application implies that numerous enterprises are still in the initial stage of digitalization and are unable to effectively integrate digital technology investment with the application layer, thereby failing to bring about digital benefits.

According to [Zhang et al. \(2022\)](#) and through the synergistic linkage with other elements to promote the digital transformation of the enterprise, top management, policy support, partnerships, and value co-creation mechanisms ([Gurbaxani and Dunkle, 2019](#)) play a central role in the process of digital transformation of enterprises. This further validates the significant impact of organizational readiness and external resources on the digital transformation. [Zuo et al. \(2010\)](#) pointed out that enterprises are the most important platform for innovation. The innovation capability of enterprises is related to the development of enterprises and the evaluation of innovation capability is one of the most concerned contents of enterprises and government departments.

The relationship between digital innovation and enterprise performance can be positively moderated through internal learning orientation and external network relationship linkage, according to [Hu \(2020\)](#), who noted this in his study. On the other hand, enterprises that actively pursue digital innovation can effectively and favorably promote enterprise performance improvement. [He and Liu \(2019\)](#) think that physical firms may increase performance through the use of digital innovation by cutting costs, increasing efficiency, and innovating. [Zhang et al. \(2014\)](#) delineate a corporate innovation roadmap that encompasses the “Three Worlds” of creativity, technology, and business; the “Three Types of Innovation” such as nuclear, chain, and source innovation; the “Three Systems” consisting of strategic, operational, and supportive frameworks; and the “Five Routes” of thought, technology, product, market, and organizational development. These components portray the innovation landscape, capabilities, construction tasks, and path choices, with the aim of guiding companies in systematically developing an innovative management system and achieving a tiered innovation capability.

2.2 Current status of digital innovation evaluation research

The renowned economist Schumpeter presents his theories on innovation in his classic work *The theory of economic development: An inquiry into profits, capital, credit, interest, and the business cycle*. In his opinion, innovation primarily involves the accumulation of capital and encompasses the following five scenarios: introduction of a new product, adoption of a novel manufacturing technique (process), exploration of a new market, identification of fresh sources for raw materials or semi-finished goods, and establishment of a new organizational structure.

Digital innovation is defined by [Weihong et al. \(2020\)](#) as the interdisciplinary efforts to reconfigure digital resources for the development of novel products, services, processes, and business models. The three primary capability modules of digital innovation encompass generation capability, transformation capability, and implementation capability as proposed by [Chen and Li \(2023\)](#), which can be utilized to assess the digital innovation capacity of manufacturing enterprises.

Digital innovation capability, as defined by [Li et al. \(2022\)](#), is a comprehensive innovation capability that integrates digital technology and encompasses both input and output capabilities of digital innovation. Building upon the concept of digitalization, [Li \(2019\)](#) constructs an evaluation index system for the digitalization of manufacturing enterprises. This system considers three aspects: digitalization inputs, digitalization applications, and digitalization benefits. It is based on a clear definition of the conceptual connotation of digitalization in manufacturing enterprises and draws upon the innovation value chain theory. [Liang and Yang \(2018\)](#) developed a comprehensive performance evaluation framework for manufacturing companies, assessing them across four critical areas: product performance, customer satisfaction, financial health, and market reach. This

3. Research methods and data collection

3.1 Research methods

Grounded Theory, introduced by sociologists Barney G. Glaser and Anselm L. Strauss in 1967, is a qualitative research method. This approach is primarily used for theory generation, especially in exploratory and social science research. It involves systematically collecting and analyzing data to identify patterns and concepts, thereby constructing new theoretical frameworks rather than validating existing ones.

Grounded Theory is characterized by several key aspects. First, theory generation is its core objective, where researchers derive and abstract concepts from data to develop theories. Second, Grounded Theory emphasizes the primacy of data. Researchers generate theories by collecting and analyzing substantial amounts of raw data, without preconceived theoretical frameworks or hypotheses. Additionally, Grounded Theory employs an iterative research process where researchers continuously reflect and refine during data collection and analysis. This process includes stages such as open coding, axial coding, and selective coding, each aimed at progressively refining and deepening the theory. Researchers must maintain a high sensitivity to the data, avoiding preconceived theories and hypotheses to ensure that the theories generated are truly “grounded” in the data. Finally, Grounded Theory employs constant comparative analysis, where researchers compare new data with previously analyzed data to discover and validate patterns, concepts, and theories, ensuring the reliability and validity of the theories.

Grounded Theory’s strengths lie in its methodological flexibility and data-driven nature. It can adapt to different research questions and types of data, emphasizing theory generation from data and mitigating the impact of researcher biases and preconceived theories on results. Through in-depth data analysis, Grounded Theory can uncover the underlying mechanisms and structures of complex social phenomena.

Grounded Theory has been widely applied in the field of social sciences, providing researchers with an effective method to explore and understand complex social phenomena. By systematically collecting and analyzing data, Grounded Theory generates new theories, offering profound insights and theoretical frameworks to the research field.

3.2 Data collection

The scope of the literature was determined using a typical sampling strategy based on the research topic of this work. The stages for the specific approach are as follows.

The first part of this study focuses on using the Knowledge Network Database to conduct a comprehensive search for academic papers related to digital innovation and smart homes, incorporating terms such as “smart home” “digital innovation” and “digital transformation”. Secondly, we commenced by conducting a comprehensive review of the abstract and full text of each article independently. Subsequently, any content irrelevant to the research question was excluded, and the list was supplemented with any references that had been initially overlooked. Ultimately, a total of 182 scholarly articles meeting our established criteria spanning from 1997 to 2023 were scrutinized. Thirdly, the Citespace software is utilized to conduct an initial word frequency analysis of 182 literary works. A significant number of function words and some high-frequency verbs in the Chinese text are excluded, resulting in a final set of 179 concept items. The dataset is then processed to eliminate irrelevant concept items and merge similar index items, ultimately yielding a comprehensive set of concept indicators.

4. Data preprocessing
4.1 Analysis of rooting theory

(1) Level 1 codes

Level 1 coding (open coding) involves the process of deconstructing original data, identifying concepts, and reassembling them in a novel manner. This necessitates setting aside personal opinions and maintaining an open mindset. We use concepts to express the interview data or literature, and borrow the concepts from the existing literature in naming the concepts, and dig into the concepts and their attributes word by word. Finally, some concepts can be grouped under concepts at a higher level of abstraction according to their properties to form categories. The Level 1 codes of digital innovation evaluation indicators are shown in [Table 1](#).

(2) Secondary coding

Secondary coding, also known as axial or mainline coding, aims to elucidate each concept and its interrelationships, integrating categories at a higher level of abstraction through iterative contemplation and analysis of their relationships.

Axial decoding does not seek to connect multiple core categories in order to construct a comprehensive theoretical framework; rather, it focuses on refining the primary categories. The goal is to further integrate the conceptual categories that have already been defined and to identify and establish their connections with one another. During axial coding, only one conceptual category is analyzed at a time in order to uncover associations with other concepts. Through the gradual analysis of each conceptual category, a network encompassing all conceptual categories can ultimately be formed. In axial coding, the most pertinent categories related to the research question are selected for analyzing relationships between main categories and subcategories. The secondary encoding of the digital innovation evaluation indicators are presented in [Table 2](#).

(3) Three-level coding

Three-level coding, also known as selective coding, involves identifying one or more core concepts from the multitude of conceptual relationships established through axial coding. These core concepts possess strong generalization, high abstraction, and robust correlation abilities, allowing them to encapsulate numerous related concepts within a broad theoretical scope.

Selective decoding, also known as developing a narrative line, is the process of distilling a core category—a story line—that can succinctly describe the entire phenomena using both the information and the generated categories, master categories, linkages, etc.

After analyzing and comparing the data, we decided to use “digital innovation” to summarize most of the categories and codes, and the story lines around this core are: technological innovation - production innovation - management innovation - sales innovation - Management innovation - Sales innovation.

4.2 Indicator-wide categorization

(1) Indicator categorization

We categorize the obtained 29 conceptual indicators (Level 1 coding) into four sub-categories (secondary coding): technological innovation, production innovation, management innovation, and sales innovation. Meanwhile, we determine digital innovation as a main category indicator (Three-Level coding). The complete set of indicators Z1 is presented in [Table 3](#) as follows: $Z1 = \{z1, z2, z3, z4\}$.

(2) Screening of key indicators

In the comprehensive set of indicators Z constructed through grounded theory, the indicators are screened based solely on existing research literature, which introduces a degree of

Open coding	Original statement	Provenance
a1 Digital technology	Digital technology continues to advance	<i>Top 100 Innovative Companies in the Digital Economy 2021</i>
a2 Intelligent Manufacturing	Deep integration of industrial technology and a new generation of information technology is the foundation of intelligent production	<i>Baihua Jiang: Exploration and Practice of Petrochemical Industry in the Field of Intelligent Manufacturing</i>
a3 Digital twin	Technologies that enable fully integrated digital twins in manufacturing	<i>A Study on the Architectural Design and Development Path of Intelligent Manufacturing Systems</i>
a4 Industrial Big Data	Full integration of supporting technologies for industrial big data smart manufacturing	<i>A Study on the Architectural Design and Development Path of Intelligent Manufacturing Systems</i>
a5 Industrial Internet	Fully integrated industrial internet allowing technologies for smart manufacturing	<i>A Study on the Architectural Design and Development Path of Intelligent Manufacturing Systems</i>
a6 CNC	The CNC system incorporates the technological innovations and intellectual property of the end user, the host factory, and the system factory	<i>Building an Open CNC Innovation Platform for Intelligent Manufacturing to Build a Community of Destiny among Enterprises</i>
a7 Internet+	“Internet + Advanced Manufacturing + Modern Service Industry” will replace traditional economic growth drivers in China	<i>“Intelligent Manufacturing - The Main Direction of ‘Made in China 2025’”</i>
a8 Green Smart Manufacturing	The first approach involves green intelligent manufacturing through R&D investments to enhance competitive advantage and reduce costs; the second approach is optimizing factor allocation for green intelligent manufacturing to improve asset utilization efficiency	<i>A Study on the Financial Effects and Internal Mechanisms of Green and Smart Manufacturing Enabling Enterprises</i>
a9 Production process model innovation	The objective is to achieve effective management of corporate production using an ideal model of the manufacturing process	<i>A Study of Smart Manufacturing Innovation Approaches to Advance Digital Transformation of Manufacturing Enterprises</i>
a10 Process Innovation	The emphasis should be on process innovation, process optimization, and the autonomy of industrial machinery	<i>Cracking the Weaknesses of Developing Intelligent Manufacturing</i>
a11 Manufacturing equipment innovation	The emphasis should be on process innovation, process optimization, and the autonomy of industrial machinery	<i>Cracking the Weaknesses of Developing Intelligent Manufacturing</i>
a12 Line innovation	11 production lines for discrete and process experience validation as well as research facilities for smart manufacturing have been constructed	<i>“Intelligent System Integration Application Experience and Verification Center Project” passed acceptance</i>
a13 Production line systems integration and comprehensive control	Improve the compressor manufacturing line’s automation, information technology, system integration, and degree of overall control in all areas	<i>A New Model of Intelligent Manufacturing for Mass Customized Production of Air Conditioning Compressors</i>

(continued)

Table 1.
Digital innovation
evaluation indicator
level 1 codes

Open coding	Original statement	Provenance
a14 Digital innovation in the supply chain	Improve the compressor manufacturing line's automation, information technology, system integration, and degree of overall control in all areas	<i>On BYD's Open Supply Chain Innovation in the Context of Smart Manufacturing</i>
a15 Flexible Intelligent Production	Investigated novel use cases for flexible intelligent manufacturing equipment	<i>Digital, Intelligent and Networked Manufacturing Development for Batch Tailored Flexible Production</i>
a16 Flexible robot production	Leading the Way to Innovation in Smart Manufacturing Digitization is a New Generation of Flexible Collaborative Robots	<i>A New Generation of Flexible Collaborative Robots Leads the Way to Innovation in the Digitization of Intelligent Manufacturing</i>
a17 Industry chain innovation	Accelerating the growth of China's intelligent manufacturing value chain is necessary to establish a complete industrial chain for intelligent manufacturing	<i>Value Chain Analysis of Intelligent Manufacturing Firms in China: Micro-Governance Structure, Evolutionary Paths and Institutional Safeguards</i>
a18 Manufacturing equipment upgrade	The paper considers the transformation of the equipment manufacturing sector and upgrading of the logic of the road to a thorough study from the perspective of the intelligent manufacturing environment	<i>A Study on Industrial Upgrading of Equipment Manufacturing Based on Intelligent Manufacturing Environment</i>
a19 Corporate mergers and acquisitions integration	Analyses of M&A requirements, motivators, integration routes, and the performance of the ensuing digital transformation	<i>An Exploration of Mergers and Acquisitions and Their Effectiveness in Manufacturing Firms from a Digital Transformation Perspective</i>
a20 Operational Innovation	Platform operationalization through innovative digital transformation	<i>Research and Exploration on Digital Transformation of Factories Based on Intelligent Manufacturing—Taking Cable and Tire Factories Under the Industrial Segment of IZP Group as an Example</i>
a21 Innovations in decision-making	Innovative digital transformation approach for datafication of decisions	<i>Research and Exploration on Digital Transformation of Factories Based on Intelligent Manufacturing—Taking Cable and Tire Factories Under the Industrial Segment of IZP Group as an Example</i>
a22 Management refinement	Through primarily digitally accelerated learning processes, the preceding phase succeeded in achieving the leapfrogging of competencies from rough management to digital management	<i>Information Technology Driving the Transformation and Upgrading of China's Manufacturing: A Longitudinal Case Study of Midea's Intelligent Manufacturing Leapfrog Strategic Change</i>

Table 1.

(continued)

Open coding	Original statement	Provenance
a23 Strategic change	Thus, in the condition of an imbalance between managerial capacity and information technology, this research suggests a theoretical model for firms to accomplish strategic transformation in smart manufacturing via leapfrogging	<i>Information Technology Driving the Transformation and Upgrading of China's Manufacturing: A Longitudinal Case Study of Midea's Intelligent Manufacturing Leapfrog Strategic Change</i>
a24 Talent development	We suggest a study on the development of digital design and intelligent manufacturing talent training models based on the history of development of the age of intelligent manufacturing	<i>A Study on the Construction of an Innovative Talent Cultivation Model Based on Digital Design and Intelligent Manufacturing</i>
a25 Product/service innovation	Innovative methods of digital transformation for new product and service development	<i>Research and Exploration on Digital Transformation of Factories Based on Intelligent Manufacturing—Taking Cable and Tire Factories Under the Industrial Segment of IZP Group as an Example</i>
a26 Market orientation	Must emphasize market-led, two-pronged approach	<i>Process Innovation in the Digital Transformation of Manufacturing</i>
a27 Internationalized development	By strengthening dual innovation skills that are internationalized, digital enablement encourages global entrepreneurial potential	<i>Process Mechanisms of Realization of International Entrepreneurial Opportunities in Smart Manufacturing Firms - A Longitudinal Case Study of Xiaomi in the Perspective of Digital Enabling</i>
a28 Cross-border integration	Starting from the actual needs of the current national consumer upgrading, based on the development trend of innovation and cross-border integration of the national manufacturing industry and the real retail industry	<i>Study on the integration architecture of "new retail + smart manufacturing" based on data platformization</i>
a29 Business model innovation	Business model is a major topic that cannot be avoided in the development process of smart manufacturing enterprises	<i>A Study on Business Model Classification, Antecedent Grouping and Performance of Smart Manufacturing Firms</i>

Source(s): Table created by authors'

Table 1.

subjectivity. Initially, an importance analysis is conducted using the relative weight of indicators. The relative weight of each criterion reflects the authors' consensus on the indicator's significance in screening data literature. The relative weight of the indicators can be utilized to screen the data in the literature, enabling authors to determine the importance of these indicators in assessing agreement. This paper conducts an initial analysis on indicator importance using their relative weights and assumes that the proposed indicators are scientifically grounded. The relative weight of the indication is C , and its range of values is $[0, 1]$. When C is closer to 1, it indicates that the indicator is more important in relation to the entire set of indicators, and when it is closer to 0, it indicates that the indicator is less important. The formula for calculating the relative weight of the indicator C is (1):

$$C_j = \frac{n_j}{\max\{n_j\}} \quad (1)$$

Spindle code	Conceptual attributes	Conceptual
A1 technology innovation	a1 Digital technology	Digital technology innovation
	a2 Intelligent Manufacturing	Intelligent Manufacturing for Business Development
	a3 digital twin	digital twin
	a4 Industrial Big Data	Precise analysis using industrial big data
	a5 Industrial Internet	Whole-process networking using the Industrial Internet
	a6 CNC	CNC systems for the coordination of CNC equipment
	a7 Internet+	Internet + mobilization of coordination capacity across equipment
	a8 Green Smart Manufacturing	Green Smart Manufacturing takes smart manufacturing a step further and promotes green enterprise development
	A2 production innovation	Optimization of the production process model
	a9 Production process model innovation	
	a10 Process Innovation	Innovation and upgrading of process models and processes
	a11 Manufacturing equipment innovation	Digital upgrading of production equipment
	a12 line innovation	Digital upgrading of production lines
	a13 Production line systems integration and comprehensive control	Digital upgrading of production line systems
	a14 Digital innovation in the supply chain	Digital upgrading of the supply chain, linking up and down the supply chain well
	a15 Flexible Intelligent Production	Application of a large number of intelligent machines and equipment to the production process
	a16 Flexible robot production	Applying Intelligent Robots to Production Processes
A3 management innovation	a17 Industry chain innovation	Break down the digital barriers upstream and downstream of the industry chain
	a18 Upgrading of manufacturing equipment	Facilitating digital upgrading of manufacturing equipment
	a19 Corporate mergers and acquisitions integration	Enterprise M&A Integration Breaks Down Digital Barriers for Enterprises
	a20 Operational Innovation	Digital innovation of enterprise operation mode, more scientific
	a21 Innovations in decision-making	Digital innovation for more science in business decision-making
	a22 Management refinement	Enterprise management from the fine and practical
	a23 Strategic change	Help companies implement their strategies more accurately by mastering and analyzing large amounts of data
	a24 Talent development	Cultivate enterprise digital innovation talents and improve enterprise management capability
	A4 Sales innovation	Digital transformation and upgrading of products/ services
	a25 Product/service innovation	Grasp market trends through massive data
	a26 Market orientation	Promoting the internationalization of enterprises
	a27 Internationalized development	
	a28 Cross-border integration	Promoting cross-border integration of enterprises and bridging the digitalization track
	a29 Business model innovation	Innovation and upgrading of the company's profit model to promote sales

Table 2.
Secondary coding of
digital innovation
evaluation indicators

Source(s): Table created by authors'

Conceptual entries	Sub-category indicators	Main category indicators
Smart Manufacturing, Digital Twin, Industrial Big Data, Industrial Internet, CNC, Internet+, Green Smart Manufacturing Production process model innovation, Process innovation, manufacturing equipment innovation, Production line innovation, Production line system integration and comprehensive control, Supply chain digitalization innovation, Flexible intelligent production, Flexible robot production, Industry chain innovation, Manufacturing equipment upgrade M&A integration, Operational innovation, Decision-making innovation, Management Refinement, Strategic Change, Talent development	Technological innovation Production innovation	Digital Innovation
Product/service innovation, Market orientation, International development, Cross-border integration, Business model innovation	Management Innovation Sales Innovation	

Source(s): Table created by authors'

Table 3.
Results of the full set of
conceptual indicator
categorization

where n_j denotes the frequency of the j th indicator and $\max\{n_j\}$ denotes the highest frequency in the full set of indicators.

Then through the expert scoring system, the importance index analysis is carried out, and the 29 index concept items are scored on five levels: 1 denoting unimportant, 2 denoting limited importance, 3 denoting average importance, 4 denoting comparatively importance, and 5 denoting extraordinary importance. An indicator entry is considered to be less significant or even irrelevant when it receives a score of 1 or 2. An indicator entry receives an average importance rating when it receives a score of 3, and an extremely important rating when it receives a score of 4 or 5. The significance score is indicated by the letter I , and its value range is $[0, 1]$. Its formula is (2):

$$I_j = \frac{A_j}{5} \quad (2)$$

where A_j represents the average expert rating for the entry with the j th indication. The important evaluation index formula from [Sha et al. \(2017\)](#) Their methodology is used to construct the key indicator importance analysis evaluation index W in this paper. The following presents the design of the detailed assessment formula for the significance index and the respective weights of the indicators:

$$W_j = C_j * I_j \quad (3)$$

In order to obtain a broad screening of key indicators, the evaluation index W of key indicator importance analysis has a value between $[0,1]$. The closer the index is to 1, the more essential the indicator is. Typically, a preset threshold c is defined, and if $W > c$, the indication is kept; otherwise, it is excluded. Following the establishment of a complete set of indicators in conceptual entries and word frequency calculations for corresponding C_j indicators, a Likert five-level scale questionnaire was administered to 40 experts and scholars to assess indicator importance. The scores were then statistically summarized to calculate I_j 's importance score and subsequently derive the comprehensive evaluation index W . Refer to [Table 4](#) on the following page for details.

Table 4.
Importance analysis of
the full set of
conceptual indicators
composite evaluation
index W results

Level 1 indicators	Secondary indicators and their weights (W)	Level 1 indicators	Secondary indicators and their weights (W)
Technological innovation	a1 Digital technology (0.055) a2 Smart manufacturing (0.881) a3 digital twin (0.018) a4 Industrial big data (0.010) a5 Industrial Internet (0.142) a6 CNC (0.008) a7 Internet+ (0.025) a8 Green smart manufacturing (0.028)	Management Innovation	a19 Mergers and acquisitions integration of enterprises (0.028) a20 Operational innovation (0.023) a21 Innovations in decision-making (0.019) a22 Management refinement (0.005) a23 Strategic change (0.032) a24 Talent development (0.033)
Production innovation	a9 Innovation in production process models (0.006) a10 Process innovation (0.008) a11 Manufacturing equipment innovation (0.010) a12 Production line innovation (0.009) a13 Production line systems integration and integrated control (0.010) a14 Digital innovation in the supply chain (0.006) a15 Flexible smart production (0.006) a16 Flexible robotic production (0.058) a17 Chain innovation (0.051) a18 Manufacturing equipment upgrading (0.005)	Sales Innovation	a25 Product/service innovation (0.044) a26 Market orientation (0.010) a27 Internationalized development (0.008) a28 Cross-border integration (0.048) a29 Business model innovation (0.005)

Source(s): Table created by authors'

Setting threshold $C = 0.015$. From Table 4, it shows that it is necessary to exclude industrial big data, numerical control system, production process model innovation, process innovation, manufacturing equipment innovation, production line innovation, production line system integration and integrated control, supply chain digital innovation, flexible intelligent production, manufacturing equipment upgrading, management refinement, market orientation, nationalized development, business model innovators 14 indicators of this concept Entry. The main conceptual entries were created by screening the important indications. After the key indicator screening, the key indicator set Z2 is created, notated as: $z2 = \{z1, z2, z3, z4, z5, z6, z7, z8, z9, z10, z11, z12, z13, z14, z15\}$.

5. Data testing and analysis
5.1 Reliability analysis

Cronbach's alpha reliability analysis was conducted to assess the internal reliability of the scale questions in the questionnaire screened for key indicators. Internal reliability refers to whether a set of questions measures the same concept in a questionnaire, that is, the degree of agreement between the group of questions. In this paper, the internal consistency test, i.e. alpha test, is used. As the value of α increases, the reliability of the evaluation system

increases, and it is usually considered that $\alpha \geq 0.7$ should be satisfied, and the formula for the reliability r is (4):

$$r = \frac{n}{n-1} \left(1 - \frac{\sum S_i^2}{S^2} \right) \tag{4}$$

The data were analyzed for reliability using SPSS software and the results are shown in [Table 5](#):

The internal consistency confidence test for the 15 conceptual entries of indicator subset Z2 yielded $\alpha = 0.949$, surpassing the threshold of 0.8 and indicating strong consistency among these indicators.

5.2 Validity tests

Validity refers to the questionnaire’s ability to accurately measure the intended target. Given the self-constructed nature of the expert questionnaire, its validity was assessed using exploratory factor analysis. Exploratory factor analysis is usually used to assess the validity of self-constructed scales. The KMO value and Bartlett’s test of sphericity can be used to determine whether the internal consistency of variables is suitable for exploratory factor analysis. High consistency of variables is more suitable for exploratory factor analysis. A lower KMO value indicates weaker internal consistency among variables, rendering them less suitable for exploratory factor analysis. The validity of this questionnaire was analyzed using the SPSS software. The data of this questionnaire were analyzed for validity using SPSS software and the results are shown in [Table 6](#).

After analyzed by KMO test and Bartlett’s test of sphericity, the overall KMO value of the questionnaire results is $0.809 > 0.5$ and $p = 0.000 < 0.05$ as shown in [Table 6](#), which makes it suitable for factor analysis and passes the validity test.

Criterion validity, content validity, structural validity, and discriminant validity are the four main testing categories for validity. The content validity test is utilized in this study to assess the conceptual content of the evaluation indicators, while the other three tests rely on the initial experiences associated with these indicators.

Cronbach alpha	Normalized term-based clone bach alpha	Item count (of a consignment etc)
0.948	0.949	15

Note(s): A reliability coefficient of 0.7 or more for the scale denotes a level of acceptability that is generally high; a reliability coefficient of 0.6–0.7 for the scale denotes a level of acceptability that is acceptable; and a reliability coefficient of less than 0.6 for the scale denotes a lower level of acceptability
Source(s): Table created by authors’

Table 5.
Reliability statistics

KMO	0.809
Bartlett’s test of sphericity	approximate chi-square (math.)
	499.060
	df
	0.105
	Sig
	0.000

Note(s): Factor analysis can only be performed when the KMO value is greater than or equal to 0.50; a KMO value below 0.50 indicates that factor analysis is not appropriate
Source(s): Table created by authors’

Table 6.
KMO and
Bartlett’s test

The content validity evaluation in this paper mainly examines the relevance of each indicator and its corresponding subcategory, so as to screen the indicators. The conceptual entries of the indicators that have been analyzed for importance are scored on a 5-point scale: 1 for not relevant at all, 2 for weakly relevant, 3 for relevant, 4 for more relevant and 5 for strongly relevant. When a score of 1 is assigned in the rating, it indicates that the indicator entry has minimal or no relevance to the subcategories. A score of 2 or 3 occurs means that the indicator entry is weakly correlated with subcategories, while a score of 4 or 5 signifies a strong correlation. The content validity index is denoted as V , with a value range of $[0,1]$, and the formula is (5):

$$V_j = \frac{M_j}{M} \tag{5}$$

where M_j denotes the number of experts who rated the j th indicator conceptual entry with 3 or 4 points, and M denotes the total number of experts involved in the scoring, usually the important criterion for evaluating the specific indicator conceptual entries is when $V_j \geq 0.78$ (Huang *et al.*, 2017) which indicates that the content validity of the indicator is superior, or it will be excluded. Table 7 shows the results of the content validity test for secondary indicators.

Then the content validity test is conducted on 15 index concept items. Following the test, it is observed that only the content validity V of the concept items exclusively related to digital twins is 0.78, but also basically through the content validity test ($V = 0.78$). Moreover, the content validity index V of other indicators exceeds 0.78 ($V > 0.78$), leading to the final index set Z being established through the content validity test. Write it as: $Z = \{z1, z2, z3, z4, z5, z6, z7, z8, z9, z10, z11, z12, z13, z14, z15\}$. Subsequently, the smart home digital innovation evaluation system is established, and the importance analysis composite index derived from the key indicators is normalized to calculate the weight of each indicator, and the calculation formula is (6):

$$A = \frac{W_j}{\sum_{j=1}^{29} W_j} \tag{6}$$

where W_j denotes the composite index of the importance analysis of the j th indicator concept entry, and through the calculation we get the evaluation system of enterprise digital innovation shown in Table 8 below.

Secondary indicators	Content validity	Secondary indicators	Content validity
a1 digital technology	0.88	a19 Corporate mergers and acquisitions integration	0.90
a2 Intelligent Manufacturing	0.80	a20 Operational Innovation	0.80
a3 digital twin	0.78	a21 Innovations in decision-making	0.83
a5 Industrial Internet	0.85	a23 Strategic change	0.83
a7 Internet+	0.80	a24 Talent development	0.88
a8 Green Smart Manufacturing	0.90	a25 Product/service innovation	0.98
a16 Flexible robot production	0.83	a28 Cross-border integration	0.88
a17 Industry chain innovation	0.95		

Table 7.
Content validity test
for secondary
indicators

Source(s): Table created by authors'

Level 1 indicators	Secondary indicators and their weights	Explicit explanation
Technological innovation	Digital technology (0.0369)	Includes technology for all segments and promotes convergence of segments
	Smart manufacturing (0.5903)	Includes technologies such as digital twins and the industrial internet, with a focus on production and distribution
	Digital twins (0.0126)	Mainly used in high-end manufacturing industries, such as aerospace technology, with low penetration in the middle and lower end of the spectrum
	Industrial Internet (0.0958)	Connecting the dots between the various segments of the manufacturing industry
	Internet+ (0.0173)	Mobilization of coordination among equipment
Production innovation	Green smart manufacturing (0.0191)	Building on Smart Manufacturing and Responding to the “Dual Carbon” Strategy
	Flexible robot production (0.0391)	Application of intelligent robots and other intelligent machines and equipment to the production process
	Chain innovation (0.0345)	Break down the digital barriers upstream and downstream of the industry chain
Management innovation	Integration of enterprises in mergers and acquisitions (0.0189)	Bridging the digital barriers between companies to facilitate strategic business development
	Operational innovation (0.0158)	Improvement of business operation efficiency through big data and other means
	Innovation in decision-making (0.0134)	Improve the scientific degree of enterprise decision-making by means of big data and other means
	Strategic change (0.0217)	Help companies implement their strategies more accurately by using large amounts of data and analyzing it
Sales innovation	Talent development (0.0223)	Cultivate enterprise digital innovation talents and improve enterprise management capability
	Product/service innovation (0.0299)	Improve sales accuracy on the sales side and find pain points to focus on
	Cross-border integration (0.0325)	Creating a new track for manufacturing and brick-and-mortar retail to converge through data platformization

Source(s): Table created by authors'

Table 8.
Enterprise digital
innovation evaluation
system

6. Results and discussion

6.1 Results analysis and evaluation system construction

The digital innovation evaluation system for smart homes is primarily reflected in four first-level indicators: technological innovation, production innovation, management innovation, and sales innovation. Based on subsequent analysis, it is differentiated into a smart home digital innovation evaluation system composed of 15 second-level indicators.

Based on extensive research and analysis of smart home digital innovation capabilities, it is evident that Chinese manufacturing enterprises have a significant opportunity to actively engage in technological, production, management, and sales innovation. By strategically allocating resources and focusing on the development of these key areas, enterprises can effectively enhance their overall innovation capacity. This fundamental promotion of enterprise innovation hinges on four crucial aspects of innovation activities: fostering a culture of continuous improvement, investing in cutting-edge technology and R&D

initiatives, nurturing talent with specialized skills and expertise, and establishing robust partnerships with industry leaders to drive enterprises towards achieving world-class digital innovation. Embracing these key aspects will enable Chinese manufacturing enterprises to stay at the forefront of digital transformation within the global market landscape.

6.2 Digital innovation empirical analysis of evaluation systems

This paper selects manufacturing enterprises listed on the A-share market from the China Stock Market and Accounting Research Database, and evaluates their digital innovation based on the scope of their business, specifically selecting smart home enterprises. We conducted a word frequency analysis of key indicators in the annual reports of selected smart home companies on the A-share market from 2015 to 2022. By integrating these indicators with the smart home digital innovation evaluation system we have established and assigning corresponding weights, we calculated the digital innovation comprehensive evaluation index for each enterprise.

Based on this index, we have divided the research subjects into five different categories. Among these categories, we specifically selected Sichuan Changhong Electric Company Limited, Guangzhou Hollco Creative Home Furnishing Company Limited, Zhibang Home Furnishing Company Limited, Beijing Sateri Technology Company Limited, and Xinya Electronics Company Limited as representative enterprises for a more in-depth analysis of digital innovation evaluation. This approach not only provides us with a framework for quantitatively assessing the digital innovation capabilities of enterprises but also helps in identifying and comparing the performance and potential of different enterprises during the digital transformation process. The overall evaluation results are as follows:

Figure 1 illustrates that smart home enterprises share a common characteristic: they prioritize technological innovation, irrespective of the level of digital innovation. However, as a company's capacity for technical innovation increases, its contribution to overall digital innovation evaluation also grows. Simultaneously, businesses are increasingly leveraging

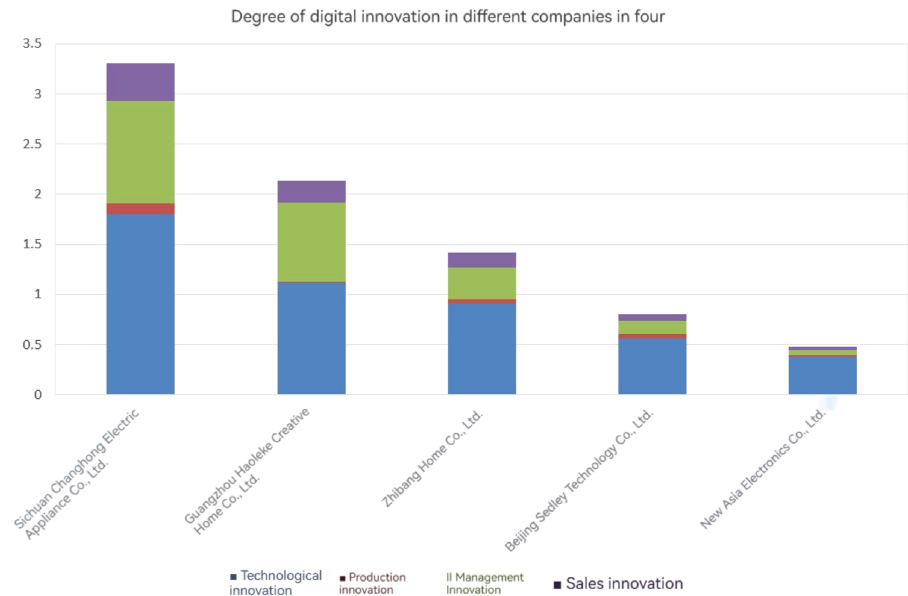


Figure 1.
Overall evaluation of
representative
companies

Source(s): Figure created by authors

digital innovation for production, management, and sales. This trend mirrors the trajectory followed by businesses with limited digital innovation. The data indicates that smart home businesses have prioritized “smart manufacturing,” “industrial Internet,” and other digital technology innovations to varying degrees. Leading smart home businesses demonstrate a high level of digital innovation not only in the field of digital technology, but also in production, administration, and sales. This suggests a path for enterprise-wide digital innovation: focusing on digital technology innovation to enhance competitiveness and achieve enterprise scale expansion, while simultaneously balancing the growth of digital innovation levels in production, management, and sales to improve enterprise effectiveness and promote the development of additional digital technologies. According to the definition of industry chain, the industry chain mainly consists of upstream suppliers, midstream manufacturers, downstream distributors and consumers. We extracted keywords related to the household industry supply chain from relevant literature, utilize software for text matching within the business scope of previously collected data from A-share listed enterprises, and categorize the matching results into upstream, midstream, and downstream segments. Then the digital innovation evaluation index of these enterprises is analyzed.

The data and Figure 2 show that, overall, downstream enterprises are more advanced in digital innovation, but there are significant variations in each firm’s level of digital innovation. Although there are significant variances in the level of digital innovation amongst businesses, upstream and midstream enterprises have slightly greater average levels of innovation than the latter.

6.3 Lateral validation of patent data to evaluate digital innovation practices

For our qualitative analysis index selection, combined with the industry technological innovation of the industry or technology field definition is dependent on the patent technology field classification (Wang, 2009), the introduction of patents as a variable to assist in proving the reliability of the research results.

During the patent screening process, to closely align the variables with the qualitative indicators, we utilized 15 keywords to search for IPC (International Patent Classification) codes related to smart home technology. We prioritized the first four IPC codes that emerged

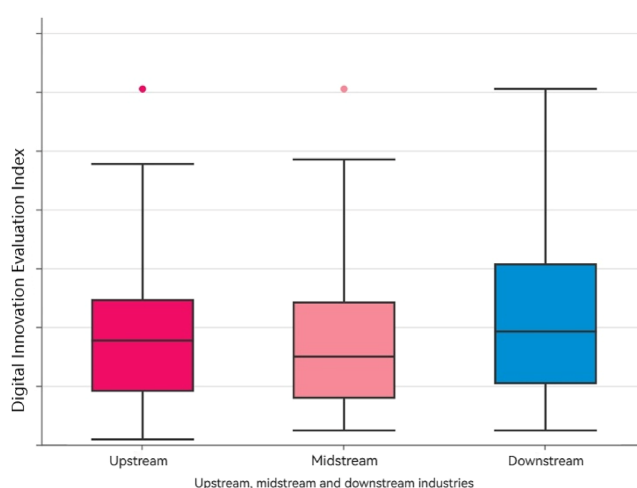


Figure 2.
Distribution of smart
home industry

Source(s): Figure created by authors

from this search and then conducted a screening in the patent database based on the patents held by the enterprises. This approach ensures a more targeted and relevant selection of patents for our analysis. By organizing and filtering the data, the number of smart home patents held by each enterprise is derived, serving as an indicator to assess the enterprise's innovation capability in the smart home sector. We selected a subset of the more successful businesses for the matching process based on data from the patent database and the smart home digital innovation index. The fact that 60% of these businesses meet the criteria for a high digital innovation assessment index and demonstrate excellent patent data further bolsters the validity of our evaluation approach. Through comparing the data from the digital innovation index with that from the patent database, we found that businesses with higher digital innovation assessment indices also possess more patents. Further analysis reveals that over 80% of all digital innovation patents are held by firms with higher head digital innovation indexes. This indicates the fairness and accuracy of the built system for evaluating digital innovation, and is validated by patent assistance.

6.4 Challenges ahead

The smart home industry, due to its sectoral constraints, has a complex industrial ecosystem that spans various fields such as home appliances, the internet, telecommunications, construction, and more. The industry chain is intricate and involves a multitude of participating companies, which presents certain challenges for the evaluation of digital innovation. As the pace of the times accelerates, technological innovation is evolving at a breakneck speed. In the smart home sector, the swift advancement of R&D in areas like the Internet of Things (IoT), artificial intelligence, and big data demands that our evaluation systems remain dynamic and continuously updated. This ensures they are in step with the latest technological shifts, reflecting the industry's ongoing transformation. A significant amount of pertinent and highly accurate official data is needed for the evaluation of digital innovation in the smart home sector.

However, due to concerns about commercial competition, corporations often keep innovation data confidential, making it challenging to obtain and resulting in lower accuracy. The industry covers a wide variety of topics, and the data is updated often and has a huge volume, making it harder to gather and complicating measurement and the creation of assessment indicators. In addition, the demand for smart home goods and services varies depending on the user base, geographic location, culture, etc., necessitating the need for the assessment system to account for these variations and adding to the evaluation's complexity.

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