

Dynamic evaluation of digital and green development policies based on text mining of the PMC framework

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Abstract: Aiming to identify policy topics and their evolutionary logic that enhance the digital and green development (dual development) of traditional manufacturing enterprises, address weaknesses in current policies, and provide resources for refining dual development policies, a total of 15 954 dual development-related policies issued by national and various departmental authorities in China from January 2000 to August 2023 were analyzed. Based on topic modeling techniques and the policy modeling consistency (PMC) framework, the evolution of policy topics was visualized, and a dynamic assessment of the policies was conducted. The results show that the digital and green development policy framework is progressively refined, and the governance philosophy shifts from a “regulatory government” paradigm to a “service-oriented government”. The support pattern evolves from “dispersed matching” to “integrated symbiosis”. However, there are still significant deficiencies in departmental cooperation, balanced measures, coordinated links, and multi-stakeholder participation. Future policy improvements should, therefore, focus on guiding multi-stakeholder participation, enhancing public demand orientation, and addressing the entire value chain. These steps aim to create an open and shared digital industry ecosystem to promote the coordinated dual development of traditional manufacturing enterprises.

Key words: digital and green development; text mining; topic modeling; policy modeling consistency (PMC) framework; machine learning

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Digital and green development have emerged as the two prominent trends as part of the contemporary global economic landscape^[1]. These elements also serve as fundamental avenues for upgrading and transforming China’s manufacturing industries. The application of open, shared, and inclusive digital technology can provide invaluable assistance to traditional manufacturing en-

terprises, enabling them to overcome the financial and technological obstacles they encounter on their path toward green development^[2]. The concept of digital and green synergistic development (i. e., dual development) has emerged as an indispensable pathway for manufacturing enterprises to address their developmental bottlenecks and cultivate sustainable competitive advantage^[3-4]. Developed countries have implemented a range of policies aimed at expediting the process of both digital and green development. For instance, the EU has issued the European Industrial Strategy, the UK has implemented the Digital Development Strategy and the Industrial Decarbonisation Strategy, and the United States has unveiled the National Smart Manufacturing Strategic Plan, accelerating dual development by promoting the open sharing of data, the integration of digital and green technology, and increasing investment in innovation.

Existing policy evaluations tend to discuss the content or structure of policies from a macro perspective^[5-6], thereby overlooking the changing characteristics of the actual targets of these policies. The effectiveness of policies in promoting the dual development of enterprises is then reflected in different links of the value chain. The value chain of manufacturing enterprises involves product development, material input, production processes, supply chain management and marketing management^[7]. Therefore, in light of the characteristics of the dual development of manufacturing enterprises, this paper constructs a policy analysis framework: policy support—external stimulation—value chain links—enterprise capability—internal selection, which addresses the external and internal factors of enterprises to clarify the logic behind policy design and identify weaknesses in current policies.

1 Research Design

The policies that facilitate the dual development of traditional manufacturing enterprises make up a complex, multi-faceted, multi-layered, and multi-level system. Drawing on the relevant literature and current developments, the study constructs an enhanced policy modeling consistency (PMC) multidimensional analysis framework, which has been augmented by the integration of the Top2Vec topic modeling method^[8]. This integration has facilitated a dynamic evaluation of 15 954 dual development-related policy texts produced at the central level in

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China. The overall research approach is illustrated in Fig. 1.

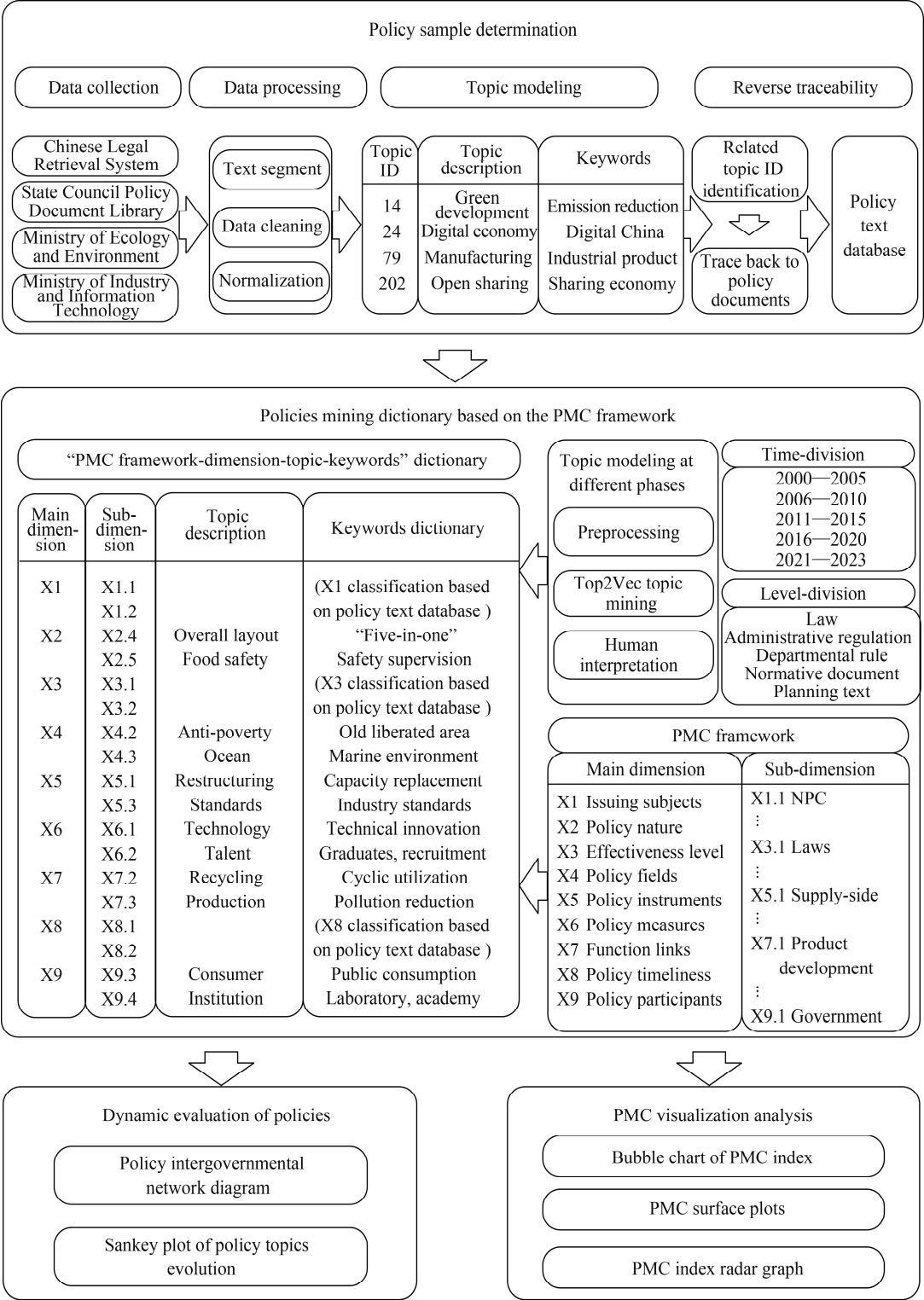


Fig. 1 Research approach

The PMC index model formulates multiple indicators to measure consistency in the policy-making process^[9]. Typically, it is made up of 9-12 primary variables and numerous sub-variables^[10]. This study identifies 9 main dimensional variables and 47 sub-dimensional variables. The external attributes of the policy include the issuing subjects (X1), policy nature (X2), effectiveness level (X3), policy fields (X4), policy instruments (X5), policy measures (X6), policy timeliness (X8), and policy participants (X9). Of these, policy nature describes whether the policy contains prediction, support, feedback, guidance, supervision, and suggestions^[11-12]. The

secondary variables of the effectiveness level include laws, administrative regulations, departmental regulations, normative documents, and planning documents. Policy fields reflect whether the policy pertains to economic, social, or environmental aspects^[13]. Policy instruments are then categorized as supply-side, demand-side, and environmental^[14]. Policy measures are specific policy measures, involving science and technology innovation, talent policy, financial policy, infrastructure, information support, consumer subsidies, product standards, government procurement, trade control and industrial ecology^[15]. Policy participants include the government, the enterprises, the public and the research institutions^[16]. The internal attributes of the policy include function links (X7), and the secondary variables of this dimension include five value chain links.

2 Policy Sample Determination

- 1) Data collection. We used a Python web crawler code to obtain policy texts. This collection excluded those local policies issued by provincial and municipal governments and ranged from January 1, 2000, to August 1, 2023.
- 2) Data processing. This involved three steps: i) text segmentation, ii) data cleaning, and iii) normalization. Following an extensive processing period, a total of 580 policy topics were extracted, each accompanied by 50 keywords.
- 3) Topic modeling. Through the process of summarizing topic keywords, abstracting topics, and eliminating irrelevant topics, 273 topics in total about the dual development of traditional manufacturing enterprises were finally chosen.
- 4) Reverse traceability. The search_document_by_topic function of Top2Vec was employed to trace pertinent policy documents following the 273 selected topics. An extensive database including 15 954 dual development-related policy texts was established. This paper conducts secondary, detailed topic modeling on the selected policy text data to identify the primary characteristics and evolutionary patterns of policies across the various dimensions in each stage.

3 Dynamic Evaluation of Policies Based on the Topic Mining

3.1 Policy-mining dictionary based on the PMC framework

- Before the analysis of policy evolution, a policy-mining dictionary based on the PMC framework was established in this study following a series of steps.
- 1) Preprocessing. Policy texts (totaling 15 954) were subject to word segmentation, data cleaning, and text structuring procedures.
- 2) Top2Vec topic mining. The Top2Vec topic model-

- ing technique was employed to generate salient document-topic-keyword distribution matrices for each phase.
- 3) Human interpretation. The phase of human interpretation involved understanding and analyzing keywords based on specialized knowledge. The specific process entailed identifying keyword sets associated with each topic and subsequently summarizing the policy topic descriptor words corresponding to these sets. Finally, the topic descriptor words were categorized into the different dimensions of the PMC framework.
- 4) A policy topic dictionary was established following the consolidation of keywords for consistently classified topics. All topics and keywords corresponding to dimensions in the PMC framework were obtained to form a “PMC framework-dimension-topic-keywords” dictionary, specifically in the field of the dual development of traditional manufacturing enterprises.

3.2 Cooperation of issuing subjects

To analyze the collaborative dynamics between policy-issuing entities, we employed a network analysis approach. We constructed a co-word matrix and imported it into Gephi, which facilitated the creation of a network graph. Fig. 2 provides a graphical representation of collaborative policy issuance among the 70 entities, excluding the National People’s Congress and the State Council. The links in the figure indicate the number of policies jointly issued between connected departments. Notably, larger nodes in the graph signify greater centrality in a department and a closer collaborative relationship with other departments. The network graph reveals a strong connection between entities such as the National Development and Reform Commission, the Ministry of Industry and Information Technology, the Ministry of Science and Technology, and the Ministry of Finance. This interconnectedness

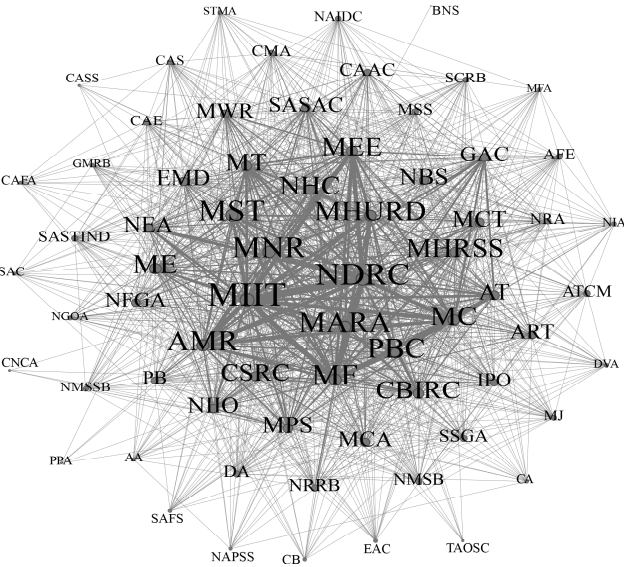


Fig. 2 Policy intergovernmental network diagram

reflects the government’s concerted efforts to leverage the unique strengths of different departments and sectors to promote the dual development of traditional manufacturing enterprises.

3.3 Policy topics evolution process

This study employs a Sankey plot to demonstrate visually the dynamic evolution of policies that facilitate the dual development of traditional manufacturing enterprises (see Fig. 3). This plot allows for an integrated analysis of the policy content issued in each phase to explore the logical progression of topics in these policies. The characteristics of the initial stage (2000—2005) are total pollution control and information construction, with supervision, supply-side policies, infrastructure and trade control identified in the Sankey plot. In the secondary stage (2006—

2010), China promoted a circular economy, and the infrastructure and production technology dimensions in the Sankey plot gradually garnered increased attention. The dimensions of support, supply-side policies, and environmental-side policies experienced a significant increment during the exploration stage (2011—2015), signifying China’s comprehensive use of policy instruments to support the dual development of enterprises. The proportion of the ecological aspect, the industrial ecology, and the public dimension was gradually enhanced during the rapid development stage (2016—2020), which indicated that the attention from the public on the ecological environment may play a vital role in this process, and the scope of these policies gradually expanded, accompanied by a more diverse array of measures and modes of governance. At the deepening stage (2021—2023), emphasis was placed

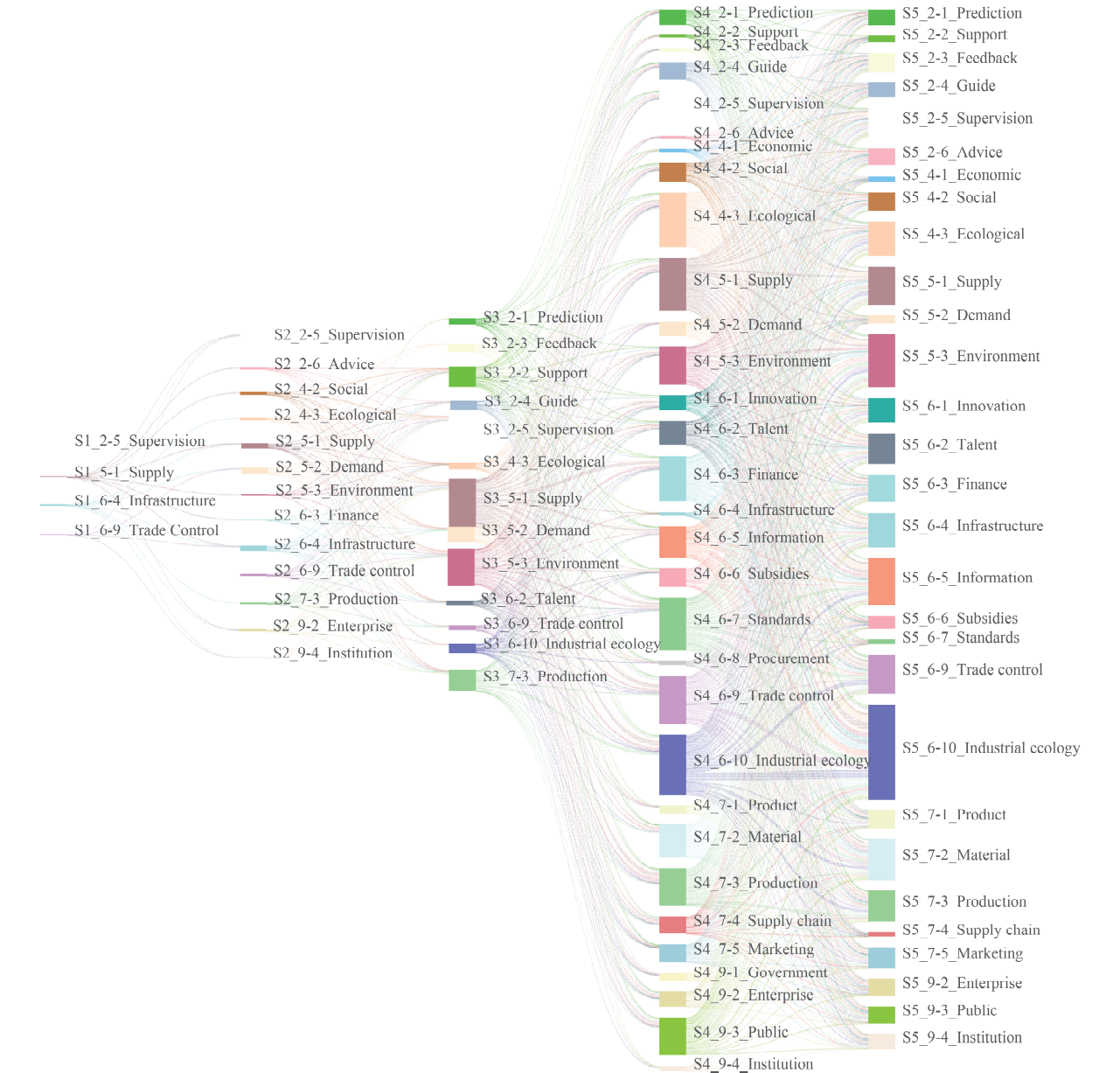


Fig. 3 Sankey plot of policy topics’ evolution in different dimensions of the PMC framework

on pilot initiatives and industrial ecosystems.

4 PMC Visualization Analysis

To explicate the specific types of policy support for the dual development of traditional manufacturing enterprises in China and identify potential shortcomings in existing policies, this paper employs the PMC policy evaluation model proposed by Estrada^[9]. In addition, the paper incorporates the topic of the previous mining-based PMC framework dictionary to calculate the PMC index for different stages. This quantitative evaluation approach thereby enables a comprehensive assessment of policy texts.

4.1 PMC index analysis

In this paper, values are assigned to all sub-dimensional variables based on the results of the topic modeling process. After analyzing the evolving patterns of PMC indices across the various stages (see Fig. 4), it is obvious that the policy framework supporting the concurrent growth of traditional manufacturing enterprises is undergoing a process of deepening and enhancement. The increasing scores in dimensions X2, X6, and X7 in the PMC framework indicate that the policy formulation process has progressed in terms of its underlying princi-

ples, has become more complex in its measures, and has grown more focused in its implementation. The fluctuations in scores for X1 and X9 shown in the figure suggest a tendency toward collaborative governance in policies that promote the dual development of traditional manufacturing enterprises.

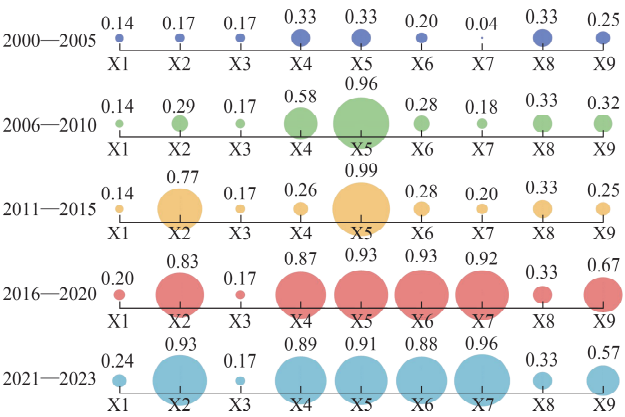


Fig. 4 Bubble chart of the PMC index

The PMC surface plot offers a visualization of the internal equilibrium of the policy at each phase, and the overall and phases PMC surface plots are shown in Fig. 5.

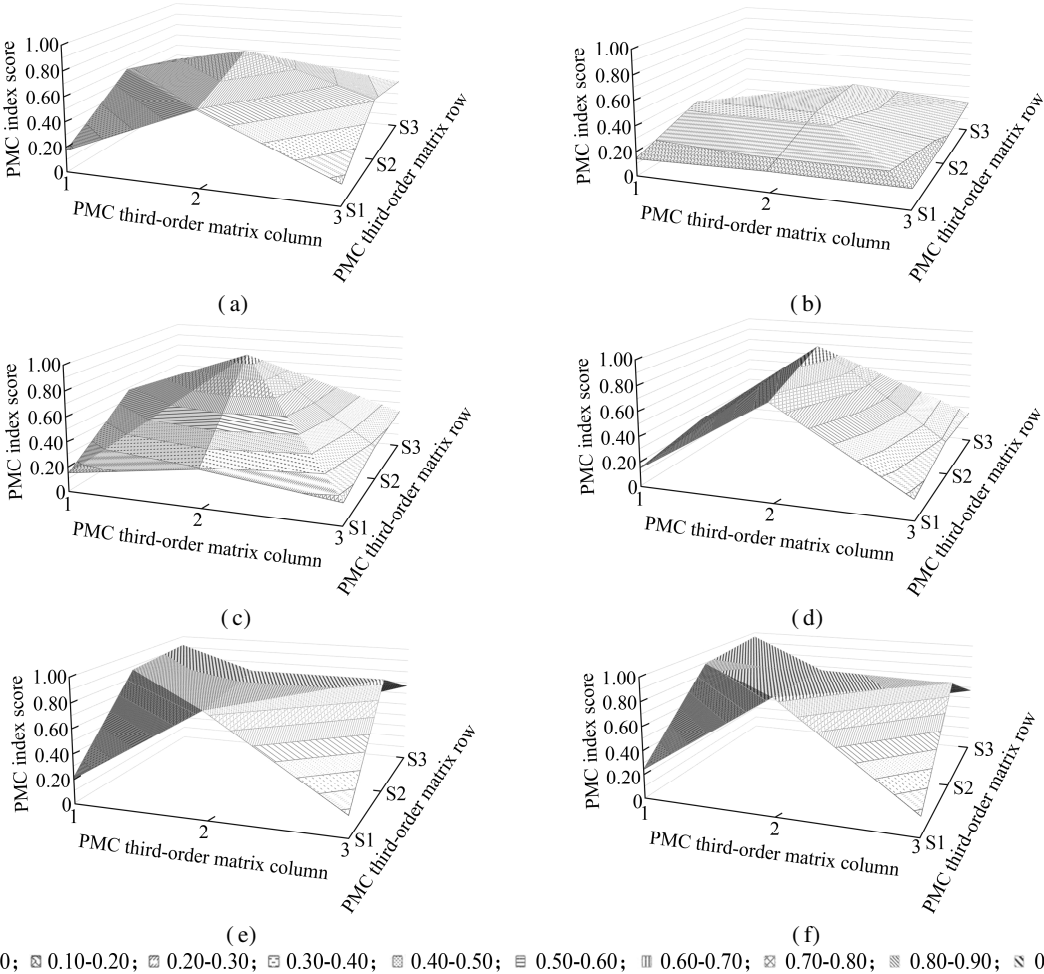


Fig. 5 Overall and phases PMC surface plots. (a) Overall average PMC index surface plot; (b) 2000—2005 PMC index surface plot; (c) 2006—2010 PMC index surface plot; (d) 2011—2015 PMC index surface plot; (e) 2016—2020 PMC index surface plot; (f) 2021—2023 PMC index surface plot

At the initial stage, the scores of all PMC main dimensions were under 0.33, indicating that China’s dual development policies were not mature in this stage (see Fig. 5(b)). At the secondary stage, the degree of convexity of the PMC surface is the most obvious (see Fig. 5(c)), and the highest point is the policy instruments dimension with a PMC score of 0.96, which indicates that the Chinese government had realized the importance of employing different types of policy instruments to solve various problems of the manufacturing enterprises. At the exploration stage (see Fig. 5(d)), the PMC score of the policy nature dimension has increased, suggesting that China has used policy types to enhance the dual development of enterprises. In the later stages (see Figs. 5 (e), (f)), the PMC surface tends to smooth out, and other dimensions have gradually developed and improved in terms of policy measures, policy fields, policy participants, etc.

4.2 PMC index radar graph

The PMC index analysis quantifies the dimensions of

X6 and X7 and produces a radar graph illustrating the PMC index of policy measures (X6) and function links (X7).

4.2.1 Policy measures dimension

As illustrated in the radar graph representing the policy measures dimension (see Fig. 6), as the dual development phase progresses, new paradigms of policy support begin to emerge, namely, information support and industrial ecology. Green data centers and industry development platforms, harnessing technologies such as the Internet of Things and big data, in addition to information service platforms, are established to provide businesses with essential information support. These initiatives cultivate an industrial ecosystem where participants pool resources, exchange services, and create value collaboratively. The relatively modest indices for consumer subsidies and government procurement indicate that the demand-side efforts were not enough.

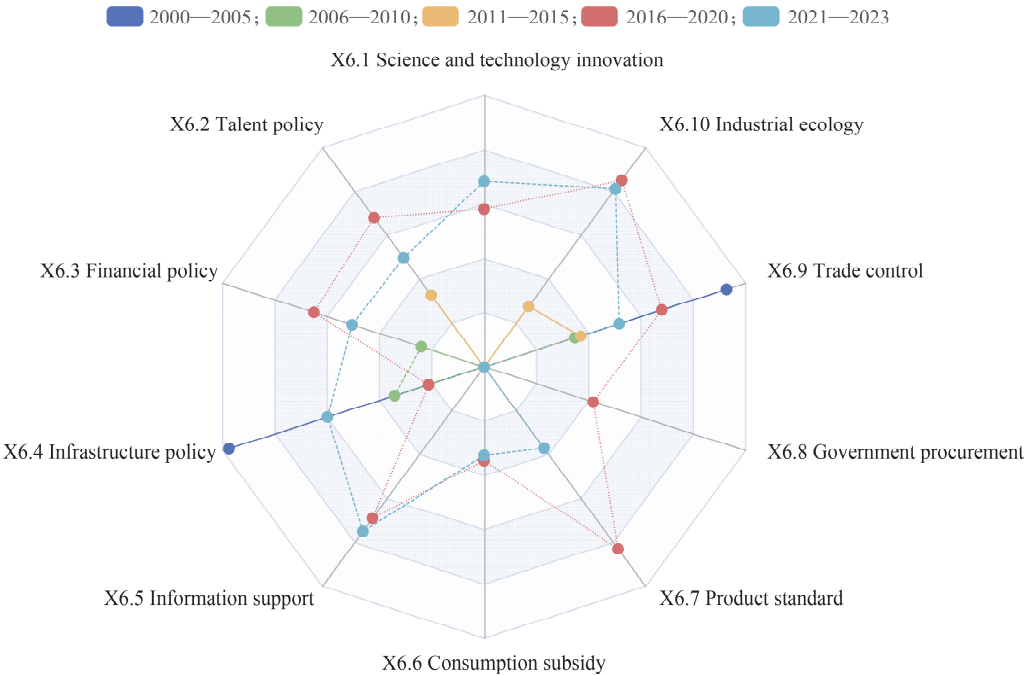


Fig. 6 Radar graph of the PMC index of policy measures (X6) dimension

4.2.2 Policy function dimension

The digital and green development of traditional manufacturing enterprises involves strategic changes and advancements along the entire value chain. It transcends isolated stage enhancements or individual processes, instead entailing a comprehensive transformation that covers the entire lifespan of the enterprise. Fig. 7 is a radar graph representing the policy function dimension, where material inputs and production processes stand out as crucial focal points supported by policy measures. The de-

velopment of greener material input relies primarily on the advancement of efficient electric heating technologies, the promotion of renewable energy sources, and the recycling of waste materials. To promote a clean and digital evolution of the production process, measures such as the establishment of intelligent green factories, research institutions, and digital infrastructure are employed. However, the PMC indices for links such as product development, supply chain, and marketing management show somewhat unfavorable performance.

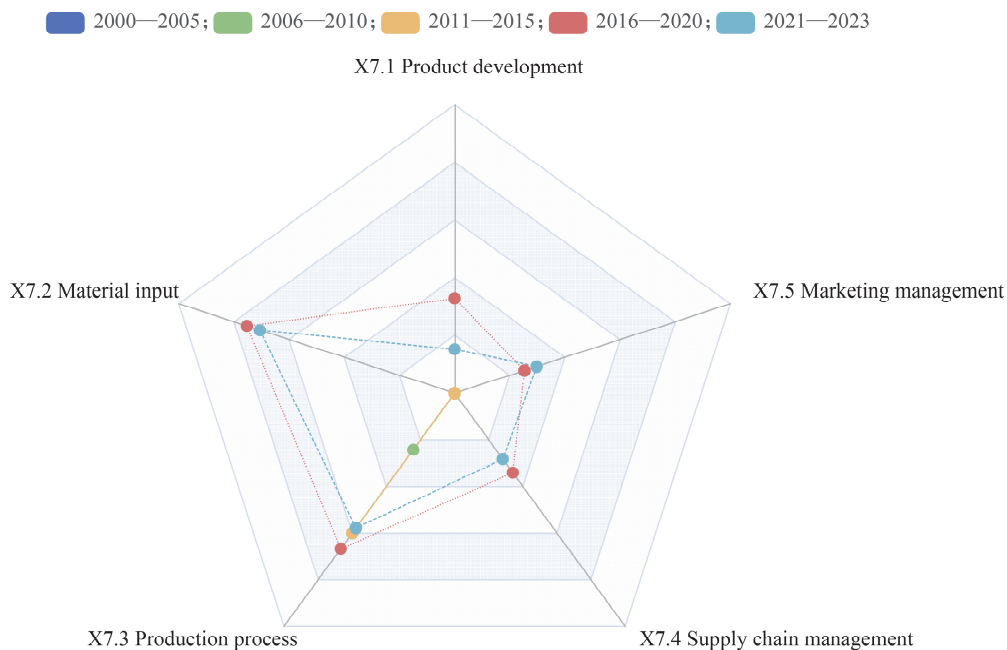


Fig. 7 Radar graph of the PMC index of function links (X7) dimension

5 Results Analysis

The policy governance philosophy has transitioned from a “regulatory government” paradigm to one of a “service-oriented government”. Frequent environmental incidents in the early stages compelled the government to implement command-type policies to regulate corporate conduct, and policy formulation followed a top-down approach. The response of enterprises to these policies influenced the evolution of the policy philosophy. With the emergence of digital technology, offering new opportunities for green development, enterprises shifted from being passive recipients of administrative directives to active agents in policy implementation.

The evolution of the policy support pattern has shifted from “dispersed matching” to “integrated symbiosis”. Under the traditional support pattern, enterprises encountered limitations in their dual development efforts due to their dependence on existing resources. With the advent of digital technology, the transition from physical to virtual resource aggregation became possible. The government responded by introducing measures to promote the integration of resources from diverse sources, levels, and content.

6 Conclusions

1) Concerning the issuing subjects of policies, there remains room for improvement in coordination between them. The government can enhance cooperation between departments, overseeing both enterprise development and those responsible for key administrative and economic resources. In addition, comprehensive coordination should be established between departments involved in digital de-

velopment and those involved in green development, involving direction, scope, and focus to enhance the integration of dual development.

2) Concerning policy measures, the predominant focus is on the supply and environmental aspects, with limited attention being given to demand-side measures. As for the green development of enterprises, the government could stimulate market demand through green product standards and green purchasing policies to enhance the market returns and strengthen the motivation for the green development of enterprises. As for digital development, the government could establish an ever-connected digitized network to better address the needs of enterprises.

3) Concerning policy participants, the government can direct its attention toward the practical requirements of manufacturing enterprises. For digital development, the government can foster digital service providers to increase the probability of successful digital transformation. For green development, efforts should be undertaken to propagate the principle of green consumption throughout society.

4) Concerning policy function links, current policies are inadequate in supporting product development, supply chain management, and marketing management. The government could establish a comprehensive cloud platform that spans the entire value chain, integrating demand signals from various enterprise stages and aligning external resource support with enterprise needs more effectively.

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基于 PMC 框架的数字化绿色化政策文本量化评价

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摘要:为了识别促进传统制造企业数字化、绿色化(双化)发展的政策主题和演化逻辑,找到政策薄弱之处,为完善双化发展政策提供借鉴,选取2000年1月—2023年8月国家及各部委颁布的15 954条双化相关政策,结合主题建模技术与PMC政策框架,可视化展现政策主题演化特征,实现对政策的动态评估。结果表明,数字化绿色化相关政策体系不断深化完善,政策治理理念由“管制型政府”向“服务型政府”转变,政策支持模式由“分散匹配”向“融合共生”发展,但在部门合作、措施均衡、环节协同和多主体参与等方面仍存在明显不足。未来政策改进方向应通过引导多主体参与、加强公众需求导向和关注全价值链环节等方面,营造开放共享的数字产业生态促进传统制造企业双化协同发展。

关键词:数字化绿色化发展;文本挖掘;主题建模;PMC框架;机器学习

中图分类号:F425;F223