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The Role of Government-Sponsored Coordination in Strengthening Manufacturing Industrial Chain Resilience: Evidence from China

Abstract: Driven by the dual dynamics of global industrial chain restructuring and high-quality domestic economic development, enhancing the resilience of industrial chains has become a crucial goal for the transformation and upgrading of China's manufacturing industry. As an innovative policy tool proposed in recent years, the "Chain Chief System" aims to strengthen industrial security and risk resistance capabilities by building cross-departmental collaborative networks. However, existing research has not yet systematically evaluated the actual effects and mechanisms of this policy on the resilience of the manufacturing industrial chain. Based on provincial input-output data from 2015 to 2022, this paper treats the Chain Chief System as a quasi-natural experiment and uses a progressive dual difference model to empirically analyze its impact on the resilience of the manufacturing industrial chain. Empirical results show that the implementation of the Chain Chief System has significantly improved the level of regional manufacturing industrial chain resilience. Moreover, this effect exhibits significant heterogeneity in the eastern coastal areas and technology-intensive industries, highlighting the structural matching relationship between policy implementation and regional development foundations and industrial characteristics. Further mechanism tests reveal that industrial collaborative innovation, optimization of the business environment, and improvement of resource allocation efficiency constitute the key pathways through which the policy exerts its effects. The research results provide policy insights for enhancing the resilience of the manufacturing industrial chain in complex economic environments.

Keywords: manufacturing industrial chain resilience; Chain Chief System; staggered difference-in-differences model

1. Introduction

The 2023 "Global Value Chain Development Report" indicates that around 2/3 of global trade volume is facilitated through industrial and value chain division systems. The contemporary model of industrial and value chain collaboration, predicated on specialized division of labor, has emerged as the primary organizational form in modern manufacturing. This model has substantially enhanced production efficiency and redefined global trade dynamics. Ensuring the resilience and security of China's manufacturing industrial chain is crucial not only for national economic security but also serves as a foundational element for stabilizing the global economic system (Shaolin 2022). The 20th National Congress of the Communist Party of China's report explicitly emphasized the need to bolster the resilience and security of industrial and supply chains, elevating the security of the industrial chain to a strategic priority for national development. Theoretically, the resilience and security of our country's manufacturing industrial chain are fundamental to safeguarding national economic security, achieving high-quality economic growth, and fostering a global industrial cooperation mechanism. They also play a vital role in advancing the construction of a secure and shared global economy. Practically, this approach is not only a strategic initiative to advance China's modernization endeavors and comprehensively build a socialist modern state but also a significant avenue for promoting optimization and upgrading.

Scientifically rigorous and precise industrial policies provide the crucial support needed to expedite the creation of a modern industrial system and bolster the resilience of the industrial chain. Currently, major economies are reinforcing their industrial policies to augment their control over the industrial chain. For instance, the United States is developing a domestic semiconductor ecosystem via the "Chips and Science Act" (Mervis 2022). The European Union is advocating strategic resource autonomy through the "Critical Raw Materials Act" (Jakimow, Samokhalov et al. 2024), while Japan is executing a "Supply Chain Resilience Plan" to foster regional capacity cooperation. In contrast to the industrial policy approaches of major economies, which typically focus on specific technologies or critical nodes, China has introduced a unique Chain Chief System (CCS) framework. This framework, characterized by "government chain leaders and enterprise chain hosts," is based on the comprehensive operational logic of industrial chains. This innovative institutional mechanism, introduced by the Party and state in the new era, aims to enhance the modernization level of industrial and supply chains (Liu Gang 2022). The role of "chain leader" is typically fulfilled by the chief executive of the local government, who represents the authority responsible for comprehensive planning of industrial chain development, cross-departmental coordination, and policy resource allocation. The "chain master" role, on the other hand, is undertaken by leading enterprises within the industrial chain. These enterprises leverage market mechanisms to play a crucial role in driving technological innovation, organizational coordination, and upstream-downstream integration. This framework's unique characteristic is the establishment of an industrial chain governance mechanism that is characterized by a division of labor and collaboration between the government and enterprises. This approach facilitates the organic integration of governmental macro-regulation with enterprise micro-level operations.

At the operational level, the CCS employs a coordinated advancement mechanism that operates "based on industrial chains as units." This approach refines industrial development objectives into actionable tasks, including supply chain completion, extension, and strengthening. The system utilizes methods such as checklist-based management, mapping-assisted diagnosis, and dedicated task force implementation to address critical constraints in industrial chain operations. As practical experience has grown, the CCS has transitioned from local exploration to national promotion. It initially emerged in certain regions through practices related to resuming work and production and coordinating industrial efforts during pandemic recovery. Its adoption was accelerated by policy document promotion, leading to locally adapted implementation models across multiple provinces. Simultaneously, the system's scope has broadened, shifting focus from short-term supply chain stabilization and security to long-term industrial chain safety and high-quality development. Strategically, the CCS seeks to enhance autonomous control capabilities and overall resilience at critical industrial chain nodes by fostering government-enterprise collaboration and systematic governance. This institutional framework improves the industrial system's ability to withstand external shocks and uncertainties while promoting deeper integration of innovation chains, industrial chains, and supply chains at higher levels. Consequently, it accelerates the construction of modernized industrial systems. In addition to safeguarding industrial chain security and stability, this system offers vital support for achieving coordinated industrial system development and enhanced competitiveness within the "dual circulation" new development paradigm.

To bolster the resilience and safety of the industrial chain, many local governments have adopted the CCS as a pioneering model of industrial governance with Chinese characteristics. While previous research has delved into the policy's impact on total factor productivity from a micro standpoint and its role in the modernization of the industrial chain, a comprehensive understanding of this institutional innovation's effects remains elusive. Specifically, it is unclear whether the CCS significantly enhances the resilience of the manufacturing industrial chain at the macro level and, if so, what its operational mechanism is. Addressing these questions not only provides an empirical evaluation of the mechanism's effects but also offers insights for refining the theoretical framework of industrial chain governance. This paper adopts a macro lens, focusing on specific industrial chains, and employs a multi-period dual difference approach. It treats the CCS as a quasi-natural experiment to examine its effects and underlying mechanisms on the resilience of the manufacturing industrial chain. Concurrently, by utilizing the PR algorithm, this study transitions from a traditional static assessment of industrial chain resilience to a dynamic network analysis. This transformation illuminates the mechanism's optimization mechanism on network topology structure by quantifying node influence and risk transmission routes.

2. Literature review and research hypotheses

2.1 Literature review

The term "resilience" originated in the field of physics, where it referred to an object's ability to absorb and transform energy to maintain its steady state when subjected to external forces and deformations. As the concept of resilience has expanded and evolved, it has transitioned from engineering resilience to ecological resilience and, most recently, to evolutionary resilience within the socio-economics field (Hosseini, Barker et al. 2016). In economics, international research on industrial chain resilience primarily adopts the perspective of supply chain resilience. It is defined as the supply chain's capacity to prepare for and mitigate unexpected risks, as well as to respond and recover swiftly and effectively from disruptions, with a focus on the system's continuous dynamic adaptability (Chari, Niedenzu et al. 2022). Conversely, domestic research tends to use the concept of industrial chain resilience, defining and analyzing it in terms of risk resistance, recovery ability, and the evolutionary capacity of the industrial chain (Zhang Wei 2023). The methodologies employed by international research on the manufacturing industrial chain predominantly include dynamic simulation (Fu, Xu et al. 2024), machine learning algorithms (Cheng, Zou et al. 2025), and network optimization models (Cheng, Wang et al. 2024, Hosseinzadeh and Taghipour 2024), among others. A review of existing literature reveals that the measurement methods for the resilience of the manufacturing industrial chain in China primarily encompass the core variable method(Fangyi 2022), comprehensive evaluation method (Fengru 2022), input-output method (He Zhengchu 2024), and more. Furthermore, Li Meng (Li Meng 2022) employed the PageRank algorithm to quantify the global embedding probability and centrality of enterprises in various regions within the industrial chain network.

Regarding the mechanisms through which manufacturing industrial chain resilience is impacted, international studies predominantly analyze from two perspectives: internal capabilities and external environment. In terms of internal capabilities, research has concentrated on longitudinal spillover effects among industrial organizations (Ge and Bao 2024) and the integration of advanced manufacturing with data analytics capabilities (Gupta, Bag et al. 2022). Studies on the external environment reveal that digital innovation technologies influence organizational resilience by altering demand dynamics (Singh, Singh et al. 2023). Furthermore, Yue (Yue, Kang et al. 2025)underscores the significant moderating role of referent power (i.e., supplier identification) in the relationship between the external environment and resilience. Domestic research primarily investigates market economy and policy factors. With respect to market economy factors, new-quality productive forces and digital transformation are continuously reshaping traditional industrial development processes, thereby emerging as critical drivers for enhancing manufacturing industrial chain resilience (Yang Haochang 2025). Regarding policy factors, the systematic promotion of industrial chain resilience construction is achieved through institutional supply innovation and the coordinated implementation of policy instruments (Sun Cheng 2024).

The development of resilience in the manufacturing industrial chain is a fundamental component of the national economic security system, with policy direction serving as the primary catalyst for this resilience (CASS 2022). Currently, strategies to bolster the resilience of the manufacturing industrial chain primarily encompass digital transformation, green transformation, and regional collaboration. Within the digital transformation policy framework, the systematic creation of industrial internet platforms and the comprehensive application of artificial intelligence technology have markedly enhanced the information acquisition and processing capabilities of each node in the industrial chain. This technological enhancement effectively reduces the response and recovery time for supply chain disruptions (Belhadi, Kamble et al. 2022, Chari, Stahre et al. 2023). The green transformation policy exerts a dual influence on the resilience of the manufacturing industrial chain. On one hand, it fosters sustainable development and augments risk resistance through measures such as energy conservation and emission reduction (Ji, Yuan et al. 2020). On the other hand, it may impose phased constraints on small and medium-sized enterprises due to transformation costs and technical barriers, intensifying the regionalization of the industrial chain (Rajesh 2018). Regional collaboration policies foster a transition from passive risk resistance to active immunity in systemic resilience through spatial network reconstruction, institutional barrier elimination, capability complementarity integration, and ecosystem co-prosperity cultivation (Saglam, Cankaya et al. 2022, Liu and Zuo 2025, Pu and Qiao 2025). To encourage innovative governance practices in the industrial chain, China has uniquely introduced the CCS, an innovative industrial governance system with Chinese characteristics. This study fundamentally explores the integration of market mechanisms and government coordination mechanisms. The government, as the primary provider of the system, creates an institutional environment utilizing policy tools. Concurrently, leading regional enterprises leverage their key position within the industry chain to encourage vertical integration. This symbiotic framework, termed "chain leader and chain master," effectively fosters the modular reorganization and networked collaboration of the industry chain's upstream and downstream components. As the depth of institutional practice continues to expand, the CCS has transformed from a localized experiment into a nationally recognized model for industrial chain governance. The literature relevant to this study primarily spans two core areas: firstly, research on the resilience of the manufacturing industrial chain, which predominantly centers on the systematic analysis of resilience measurement methods and their contributing factors; and secondly, research on the policy driving mechanism for enhancing resilience in the manufacturing industrial chain. Given that the CCS is primarily oriented towards China and has only been in place for a relatively short period, there are limited scholars currently focusing on it. Most studies approach it from a qualitative perspective, with a notable absence of quantitative analysis. Furthermore, research that incorporates the CCS and manufacturing industrial chain within the same analytical framework remains unexplored.

2.2 Research hypotheses

2.2.1 Analysis examining the impact of CCS policies on the resilience of manufacturing industrial chains

The CCS, an innovative practice within China's socialist market economy, has emerged as a pivotal policy tool for regional industrial chain development through the "government-market" collaborative governance mechanism. This system is spearheaded by top-level government design and focuses on market-driven main chain enterprises, thereby constructing a dynamic "policy-industry" matching mechanism. On one hand, it fosters a collaborative innovation network by enhancing the efficiency of factor allocation and solidifying the dominant position of the main chain enterprises within the industrial chain. Conversely, it systematically boosts the comprehensive efficiency of supplementing short boards, extending chains, stabilizing nodes, and fortifying advantages in the industrial chain by relying on the clustered development of industries (Lanxin 2024). It is imperative to note that due to the pronounced industrial gradient differences in China's regional development, the effectiveness of the CCS may exhibit spatial heterogeneity. The eastern region, endowed with early advantages and a robust industrial foundation, exhibits significantly better policy effects than the western region (Zhao Jianji 2023). This "one place, one policy; one industry, one policy" precise policy-implementation mode not only exemplifies the regional adaptability of institutional design but also reflects the flexibility of the CCS as a novel type of industrial policy tool. Consequently, we propose the research hypothesis:

H1: The implementation of the CCS can augment the resilience of the manufacturing industrial chain in the region where it is implemented.

H2: The impact of the CCS on the resilience of the manufacturing industrial chain exhibits heterogeneous characteristics.

2.2.2 Analyzing the mechanism by which the CCS influences the resilience of manufacturing industrial chains

The resilience of industrial chains pertains to their dynamic ability to maintain stability, recover development, and achieve upgrading in the face of external shocks. This resilience is primarily supported by the economies of scale and knowledge spillover effects generated through industrial agglomeration. By optimizing the division of labor structure, reducing transaction costs, and encouraging the flow of innovative elements, collaborative agglomeration significantly bolsters the risk resistance and innovation efficiency of industrial chains (Liu, Xu et al. 2024). The concept of "chain-chief production," an institutional innovation, integrates cross-departmental resources and breaks down information barriers. This constructs a collaborative governance framework of "national strategy-regional implementation" (Lingchi 2021), thereby achieving the dual objectives of enhanced industrial chain resilience and optimized market operation efficiency while simultaneously improving resource allocation efficiency. Drawing upon the preceding analysis, we put third hypothesis

H3: The implementation of CCS policies could enhance industrial agglomeration, foster innovation and research, and augment the resilience of the manufacturing industrial chain.

A robust infrastructure, accessible public transportation, and a fair, transparent regulatory policy environment are essential components of a healthy policy environment. These institutional foundations bolster the risk resistance of enterprises while ensuring their sustainable development (Song, Zhu et al. 2025). From an endogenous industrial chain development perspective, optimizing the business environment enhances labor market matching efficiency, mitigates information asymmetry, and fosters effective alignment between human capital and market demand. In the external environment, a diversified financing system and standardized market competition order not only augment the stability of corporate finances but also stimulate innovation, driving regional economic development of high quality (Wu, Zhu et al. 2023). The innovative policy constructs a collaborative mechanism between a "proactive government" and an "effective market," thereby establishing a favorable business environment and providing institutional support for the development of a modern industrial system. Drawing upon the preceding analysis, we introduce the hypothesis:

H4: The adoption of the CCS has the potential to bolster the resilience of the manufacturing industrial chain through the optimization of the business environment.

Enhancing resource allocation efficiency is pivotal for optimizing the operational efficiency of industrial chains. Firstly, by constructing a comprehensive digital map, the system integrates crucial information elements such as technical routes and supply-demand relationships of enterprises both upstream and downstream, significantly mitigating transaction costs associated with information asymmetry (Chen and Yu 2024). Secondly, through the institutionalized development of a government-enterprise data-sharing platform, there is collaborative integration of multi-dimensional governmental data from sectors such as industry and commerce, taxation, and customs, thereby enhancing the timeliness and accuracy of information procurement (Ning, Li et al. 2023). Finally, the establishment of an inter-organizational talent-sharing mechanism ensures optimized allocation of capital elements and human resources. This not only addresses financial constraints in pivotal areas but also fosters a synergistic innovation ecosystem encompassing industry, academia, and research (Nikookar and Yanadori 2022). Concurrently, the CCS refines regional element layout and nurtures backup suppliers via a "government-market-enterprise" collaborative approach. Additionally, it aggregates innovative elements through the "chain leader + fund" model, stimulates the diversified advancement of technology, reduces the R&D cycle, and further refines the innovation ecosystem. Based on the preceding analysis, we introduce the hypothesis:

H5: The adoption of the CCS can bolster the resilience of the manufacturing industrial chain by optimizing resource allocation efficiency.

Integrating the aforementioned analyses, this study presents a conceptual framework delineating the mechanism through which the CCS influences the resilience of the manufacturing industrial chain (Figure. 1).

3. Research design

3.1 Model setting

The Difference-in-Differences (DID) approach has emerged as a predominant econometric methodology for assessing policy implementation effectiveness in recent years. Representative applied studies are listed in Supplementary Material Table 1.Within the framework of progressively enacted the CCS, the DID method adeptly harnesses both cross-sectional variations across provinces pertaining to their policy adoption status and temporal shifts before and after the policy's enactment within identical provinces. In any specific year, provinces that have adopted the CCS are categorized as the treatment group, whereas those pending implementation form the control group. By juxtaposing alterations in manufacturing industry supply chain resilience between these groups pre and post policy initiation—while accounting for fixed effects related to both province and year—the technique can precisely discern the net impact of the CCS on manufacturing industrial chain robustness. Consequently, the CCS functions as a "quasi-natural experiment," facilitating the application of the DID method for policy appraisal. Given the varied timing of CCS adoption among provinces, this research adopts a staggered difference-in-differences model for its evaluation.

Specifically, the policy implementation variable did_{it} is constructed by using the year when each province first officially issued its CCS policy document as the policy initiation time. If province i has implemented the CCS policy by year t, then did_{it}=1; otherwise, did_{it}=0. Therefore, in any given year, provinces that have implemented the CCS constitute the treatment group, while those that have not yet implemented it form the control group. Following established research methodologies (Egami and Yamauchi 2023), the baseline regression model is specified as follows:

$$PR_{it} = \alpha + \theta did_{it} + \lambda X_{it} + \varphi_i + \mu_t + \epsilon_{it} \tag{1}$$

Among them, PR_{it} denotes the resilience of industrial chains in manufacturing of province i at time t; did_{it} is a variable indicating whether the "CCS" has been implemented or not, which equals to 1 if the CCS was implemented in province *i* at time *t* and 0 otherwise; X_{it} represents a set of control variables; φ_i captures provincial fixed effects; μ_t indicates year fixed effects; ϵ_{it} is the stochastic disturbance term; α is the constant term. The estimated coefficient θ measures the impact effect of the CCS on the resilience of industrial chains in manufacturing.

3.2 Variable setting and data selection

The dependent variable in this paper—the resilience of the manufacturing industrial chain—is conceptualized using Li Meng's (2022) measurement approach, specifically from an industrial chain network structure perspective. Each province is treated as a node in the directed manufacturing industrial chain network, and a multi-layered industrial chain network is constructed based on input-output relationships. The embeddedness degree of each node within the global industrial chain network is calculated under conditions involving multiple referential and referred relationships.

To this end, this paper uses the PageRank (PR) algorithm to calculate the global embedded probability of each provincial node in the manufacturing industrial chain network. Let OD_i be the out-degree of industry in province *i* and

PR_i is the enterprise PageRank value of province i, which can be calculated by:

$$PR(l(j=i|t+1)=\frac{1-q}{N}+q\sum\nolimits_{i\in\{1,2,\cdots,N\}}\frac{PR(l(j=i|t)}{OD_i} \tag{2}$$

The set element consists of N regions, with q as the damping coefficient. The PageRank value not only signifies the positional importance of a node within an industrial chain network but also integrates the structural characteristics of its connected nodes through a recursive mechanism. As such, it effectively captures both the global embeddedness and structural significance of regions in manufacturing industrial chain networks. In this study, PR values are utilized as proxy indicators for the structural dimension of resilience in manufacturing industrial chains: A higher PR value for region *i* suggests that it occupies a more pivotal and robust position within the network, thereby indicating a greater capacity to sustain operations and mitigate risks during external disruptions.

The core explanatory variable, the chain-head enterprise policy, was first implemented in Hunan Province in 2018 and gradually expanded to all provinces across the country. This study selects 30 provinces where the manufacturing industry is covered by the chain-head enterprise policy, except Tibet, Taiwan, Hong Kong, and Macao due to data availability issues. Informed by the works of Li Shiheng (Li 2022) and He Zhengchu, this research identifies factor endowments, human capital, infrastructure level, and industry concentration as key control variables. Notably, human capital is quantified by the average years of education, factor endowments are assessed by the ratio of capital stock to the number of employed individuals, infrastructure level is represented by per capita urban road area, and industry concentration is denoted by the Herfindahl-Hirschman Index.

This study, due to data availability, spans the years 2015-2022. The primary dependent variable—the resilience index of the manufacturing industrial chain—is derived through calculations based on data extracted from "Statistical Yearbooks" and "Input-Output Tables" corresponding to each province. The key explanatory variable details—implementation timelines of the CCS across various provinces and their applicable industries—are sourced directly from official government documents. Control variables' data is principally obtained from the "Statistical Yearbook," with the Hirschman Index calculation method being a reference to the research methodology utilized by Jiang Fuxiu (Jiang Fuxiu 2019). To maintain data consistency and comparability, standardization techniques were applied, and suitable methods were employed to fill in missing values. During the path analysis, we noted a significant data gap for key variables in the Tibet Autonomous Region. Consequently, samples from this region have been excluded from the empirical analysis to maintain the study's integrity and accuracy.

4. Analysis of empirical results

4.1Parallel trend test

The efficacy of the DID model is fundamentally dependent on the validity of the parallel trends assumption. This assumption suggests that, prior to the policy implementation, the outcome variables of both the experimental and control groups should demonstrate a relatively consistent trend. The method can be articulated as:

$$PR_{it}=\alpha+\sum_{-3}^{4}\delta_t\,treat_{it}+\lambda X_{it}+\varphi_i+\mu_t+\epsilon_{it} \tag{3}$$

Among them, $treat_{it}$ represents a set of dummy variables that assume a value of 1 if province i implemented a pilot policy of the CCS in the manufacturing industry in year t, and 0 otherwise. The definitions of the remaining variable symbols are consistent with those in formula (1). The parallel trend test primarily examines the coefficient δ_t, which denotes the difference in resilience of the manufacturing industry chain between the experimental and control group provinces in the year of policy implementation.

This paper takes the three pre-implementation periods as the base period, mainly based on a comprehensive consideration of the characteristics of the sample support set and institutional background. Specifically, the chain responsibility system presents obvious phased implementation at the provincial level, and most regions officially implement it between 2020 and 2022. In this case, if only one pre-implementation period is taken as the base period, then this period is more likely to be in the stage of policy preparation and organizational mobilization, which makes it easy to produce cross-provincial learning spillover and collaborative governance spillover effects in the process of gradual promotion throughout the country, thus affecting the "cleanliness" of the untreated base period. At the same time, considering that the sample interval is from 2015 to 2022, and the policy implementation is concentrated in recent years, the natural year corresponding to the three pre-implementation periods (mainly within 2017–2019) can cover more implementation cohorts, which helps to build a more balanced and stable event study window and improve the robustness of dynamic effect identification. Based on the above institutional background, sample constraints, and reference to the mature methods used in existing studies (Xing 2022), this paper finally takes the three pre-implementation periods as the base period.

The parallel trend test results are plotted in Figure 2. The estimated coefficients before the policy implementation are generally insignificant, suggesting no systematic difference between treatment and control groups before the policy implementation and confirming the overall validity of the parallel trend assumption. At the same time, the pre-implementation coefficients show a slight upward trend in the figure, which may be due to factors such as policy preparation activities, learning diffusion during gradual rollout, measurement errors in implementation timing, and confounding effects from industrial trends occurring simultaneously. In addition, the insignificant estimate observed at period $t = 4$ after policy implementation is mainly due to insufficient effective sample support under distant event time horizons. The sample period of this study spans 2015–2022, while most provinces implemented the CCS during 2020–2022. As a result, fewer provinces contribute observations at $t = 4$, leading to larger standard errors and wider confidence intervals. The positive point estimate remaining statistically insignificant more likely reflects an inadequate identification capacity for distant periods rather than definitive evidence of zero long-term effects. Methodological literature on event studies highlights that with limited sample periods and staggered adoption timing, distant event windows often exhibit unstable identification due to insufficient sample support (Schmidheiny and Siegloch 2023). Moreover, within robust inference frameworks that allow for some degree of nonparallel trend deviations, uncertainty in estimating treatment effects increases with longer event time horizons, making distant estimates more susceptible to confidence interval expansion rather than effect attenuation (Rambachan and Roth 2023).

4.2 Benchmark regression results

Table 1 presents the effects of the CCS on the resilience of manufacturing industrial chains in pilot provinces. The findings reveal that, irrespective of control variable inclusion, the coefficient estimates for the dummy variable representing the CCS are notably positive and withstand statistical testing at the 1% significance level. This suggests that the CCS substantially enhances the resilience of the manufacturing industrial chain across different regions. One potential explanation is that the policy bolsters knowledge spillover and technology diffusion by encouraging production agglomeration within the regional manufacturing sector, thereby refining the allocation efficiency of production factors. The implementation of the CCS has notably enhanced the business environment while fostering collaborative innovation among various entities. In this context, the government, serving as the chain chief, has strategically optimized the industrial chain layout, significantly reducing operational costs and potential risks through effective resource allocation and macroeconomic regulation. Concurrently, core companies, operating as chain masters, have elevated the overall efficiency and competitiveness of the industrial chain by spearheading technological innovation and actively promoting collaboration with their upstream and downstream partners. Consequently, research hypothesis 1 has been empirically verified.

Table 1 Benchmark regression results

	(1)	(2)
VARIABLES	PR	PR
did	0.0096***	0.0070**
	(0.0029)	(0.0028)
infrastructure		-0.0018***
		(0.0004)
Human-capital		0.0130**
		(0.0056)
Factor-endowment		-0.0008***
		(0.0003)
HHI		0.0367**
		(0.0157)
ID FE	Yes	Yes
Year FE	Yes	Yes
Observations	248	248
Adj. R-squared	0.8756	0.8897

Note: (1) ***, **, and * respectively represent the significance levels of 1%, 5%, and 10%; (2) The values in parentheses are t-values. The same below.

4.3 Placebo test

4.3.1 Time placebo test

To ensure the resilience differentials in the manufacturing industrial chain between the experimental and control group provinces aren't attributed to temporal changes, this study adjusts the implementation time of the CCS by 4, 5, and 6 years. These artificial timelines are represented as did_4, did_5, and did_6. Regression analysis on Equation (2) reveals that the coefficient estimates for did_4 and did_5 are positive, while that for did_6 is negative. However, none of these estimates are statistically significant in Table 2. This suggests that advancing the policy's implementation time does not significantly enhance its effect on the resilience of the manufacturing industrial chain. In conclusion, the study has withstood a placebo test with an accelerated processing time.

Table 2 Time placebo test

	(1)	(2)	(3)
VARIABLES	PR	PR	PR
did_4	0.0043		
	(0.0033)		
did_5		0.0028	
		(0.0042)	
did_6			-0.0014

			(0.0080)
Controls	Yes	Yes	Yes
ID FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	248	248	248
Adj. R-squared	0.883	0.882	0.882

4.3.2 Individual placebo test

To mitigate the impact of unobservable variables on the benchmark regression results, we adopt the placebo test approach, as utilized by Cai. We randomly select provinces from the sample set to serve as false experimental groups, mirroring the size of the original experimental group. The remaining provinces are designated as false control groups. A placebo test is then performed between these two groups. This procedure is repeated 1000 times, and the resulting regression coefficients and their corresponding p-values are visualized through kernel density distribution maps The Figure 3 illustrates that the regression coefficients cluster closely around zero and adhere to a normal distribution, with the majority of the regression outcomes being statistically insignificant. In conclusion, the results have withstood the individual placebo test.

4.4 Other robust tests

4.4.1 Identification of Dynamic Treatment Effects under the Staggered Implementation Policy

Considering that the implementation of the chain responsibility system in different provinces was not synchronized and showed a staggered adoption pattern, regions that had already implemented the policy might repeatedly serve as control groups in subsequent periods under the traditional multi-period DID (Difference-in-Differences) framework. This characteristic could introduce potential estimation bias when treatment effects exhibit heterogeneity. To examine the robustness of baseline regression results under more flexible and reasonable identifying assumptions, this paper further employs an improved parallel trends test method proposed by Callaway and Sant'Anna (Callaway and Sant’Anna 2021) (hereafter referred to as CS-DID) for supplementary validation of core conclusions. This approach groups observations based on the timing of each region's initial policy implementation, selecting only regions without policy exposure as the control group in each period. By doing so, it effectively avoids the "already treated units serving as controls" issue inherent in conventional multi-period DID designs, thereby providing a more robust characterization of dynamic average treatment effects under staggered policy implementation contexts.

The CS-DID estimation results indicate that prior to policy implementation, none of the estimated coefficients across periods demonstrated significant anticipatory effects or critical period jumps, thereby supporting the parallel trends assumption. Following policy implementation, the treatment effect proved significantly positive and exhibited dynamic characteristics of gradual strengthening over time, suggesting that the CCS exerts a persistent and cumulative impact on regional manufacturing industrial chain resilience. Overall, the CS-DID estimation outcomes align consistently with the benchmark multi-period DID results in both directional interpretation and statistical significance. This consistency demonstrates that our conclusion regarding the CCS's enhancement of regional manufacturing industrial chain resilience is not driven by staggered policy implementation timing or selective entry effects, but rather maintains strong robustness. Detailed estimation results (Dynamic Effect result) are presented in the Appendix.

4.4.2 Sample data filtering

The benchmark regression results presented above suggest that the implementation of the CCS significantly bolsters the resilience of the manufacturing industrial chain. However, to mitigate the potential impact of extraneous factors on the research conclusions, a series of robustness tests are warranted. This paper therefore adopts a multidimensional analysis approach, which includes sample data screening, time trend control, exclusion of interference from other policies during the research period, and propensity score matching. These measures collectively serve to fortify the robustness of the estimated results.

This study employs both 1% and 5% tail-cutting treatments on the research samples in order to mitigate the impact of outliers on the benchmark regression results. The reanalysis of model (1) following these treatments provides a robustness check. The results in Table 3 reveal that with a 1% tail-cutting treatment, the coefficient estimate for the key explanatory variable is 0.074, successfully passing the statistical test at the 1% significance level. Similarly, the 5% tail-cutting treatment also sees the key explanatory variable pass the statistical test, this time at the 5% significance level. The consistency of these findings with the initial benchmark regression results serves to further validate the robustness of the CCS positive effect on enhancing the resilience of the manufacturing industrial chain.

Table 3 Sample data tail-shortening processing

	(1)	(2)
VARIABLES	1% tail reduction	5% tail reduction
did	0.0074***	0.0039**
	(0.0023)	(0.0020)
Controls	Yes	Yes
ID FE	Yes	Yes
Year FE	Yes	Yes
Observations	248	248
Adj. R-squared	0.915	0.917

4.4.3Eliminate other policy interference

To mitigate the potential influence of concomitant policies on the resilience of the manufacturing industrial chain during the research period, which could skew the benchmark regression results, this study conducted a comprehensive review of relevant documents. Through this review, we identified a policy that could significantly impact the resilience of the manufacturing industrial chain: the "Guiding Opinions of the Ministry of Industry and Information Technology on Further Promoting the Development of Industrial Clusters." To account for the potential distractions from other experimental policies during the implementation of the CCS, we incorporated a dummy variable (Cluster) into the benchmark regression model. A value of 1 for Cluster denotes that the province adopted the industrial cluster development policy in the respective year, while a value of 0 indicates otherwise. Our findings, in Table 4 after controlling for the effects of this policy, align with the original benchmark regression results.

Table 4 Excluding Other Policy Interference Results

	(1)
VARIABLES	PR
Cluster treat×time	0.0073**
	(0.0029)
Controls	Yes
ID FE	Yes

Year FE	Yes
Observations	248
Adj. R-squared	0.887

4.4.4 Time trend item control

This paper seeks to eliminate the potential impact of systematic changes over time on the resilience of the manufacturing industrial chain, as well as to ensure the reliability of the baseline regression results. To achieve this, we introduce a time trend control variable in order to test the robustness of the baseline regression findings. The purpose of including the time trend variable is to account for the effects of technological advancements, macroeconomic fluctuations, and other systemic factors that evolve over time on the resilience of the industrial chain. By controlling for the time trend, we can effectively isolate the independent influence of the CCS on the resilience of the industrial chain while also mitigating endogeneity concerns related to the time dimension.

Table 5 Time trend item control result

	(1)
VARIABLES	Time trend item control
did	0.0070**
	(0.0028)
Controls	Yes
ID FE	Yes
Year FE	Yes
Observations	240
Adj. R-squared	0.890

The regression analysis in Table 5 reveals that, even after accounting for the time trend variable, the influence of the CCS on the resilience of the manufacturing industrial chain remains statistically significant. Notably, the coefficient directions of the core variables align with those of the baseline model. These findings suggest that the CCS possesses robust capabilities in enhancing the resilience of the industrial chain, and its estimated outcomes are not biased by the time trend.

4.4.5 Propensity matching score test

Endogeneity issues, often stemming from reverse causality and sample selection bias, can significantly impact the reliability of research findings. In this study, the potential endogeneity bias due to reverse causality is substantially mitigated given that it is unlikely for the explained variable—the resilience of the manufacturing industrial chain—to exert a reverse influence on the core explanatory variable, which is the CCS. This paper also employs the propensity score matching DID model, as per the research methods of Cao Xiguang (Guangxi and Min 2024), to address endogeneity issues related to sample selection bias. Additionally, a robustness check is conducted. Given the smaller sample size of the experimental group and numerous matching variables, a 1:5 nearest neighbor matching approach is adopted to prevent excessive data loss from unsuccessful matches. Regression analysis is performed on the matched samples, and the results in Table 6 indicate that the coefficient estimates of the interaction term pass the significance test after utilizing the 1:5 nearest neighbor matching method, the caliper matching method, and the Mahalanobis distance matching method. This further substantiates the notion that the CCS has bolstered the resilience of the manufacturing industrial chain.

Table 6 Propensity matching score result

	(1)	(2)	(3)
	Calipers matching	Nearest neighbor matching	Mahalanobis distance matching
treat#time	0.0086*	0.0195*	0.0175**
	(0.0048)	(0.0094)	(0.0068)
Controls	Yes	Yes	Yes
ID FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	0.0485	-0.1030	0.1600
	(0.1230)	(0.2068)	(0.1797)
Observations	162	75	75
R-squared	0.935	0.916	0.936

5. Heterogeneity analysis

5.1 Geographical location regression

This paper first addressed the marked disparities across various regions of the country regarding the implementation stage of the CCS and the position of the manufacturing industrial chain. It employed a 1% tail-cutting treatment on the data as an initial step. Subsequently, provinces were categorized based on their geographical location into eastern, central, and western regions. Relevant tests were conducted for each region, with the regression results displayed in Table 7. The coefficient estimate for the eastern region was 0.0102, withstanding the systematic test at a 5% significance level. Similarly, the central region, with a coefficient estimate of 0.032, also withstood the statistical test at a 5% significance level. However, the western region, with a coefficient estimate of 0.0002, failed to pass the significance test statistically.

The regression analysis from various geographical locales indicates that the CCS influence on the resilience of the manufacturing industrial chain is notably pronounced in the eastern and central regions. However, its impact remains statistically insignificant in the western region. The eastern region, being a pioneering area, boasts extensive policy experience and a robust synergy between institutional execution and market mechanisms. This region swiftly addresses industrial chain bottlenecks through a nuanced policy mechanism guided by leading cadres. Furthermore, it capitalizes on established industrial clusters and factor markets, ensuring an efficient alignment of policy resources with industrial needs. As a result, the eastern region exhibits superior supply chain adaptability and technological innovation resilience when confronted with external disturbances. In the central region, the marked effectiveness can be attributed to the meticulous execution of industrial transfers and the seamless integration of regional factors. By gradually undertaking industrial transfers from the east, the region rapidly enhances its industrial chain. Concurrently, it cultivates an adaptive industrial ecosystem that leverages its labor and logistical advantages. This strategic "undertaking-adapting-upgrading" approach empowers the central region to bolster its resilience by fine-tuning industrial chain organization, even with a comparatively modest R&D investment. Conversely, the western region commenced its policy implementation at a later stage. Moreover, the region's fragmented industrial chain network and dearth of supporting enterprises might impede the policy's potential synergistic effects. The region's lower concentration of innovative elements and its reduced marketization level further constrain policy transmission efficiency. Thus, the beneficial outcomes of these measures will likely take time to manifest.

Table 7 Results of geographical location regression

	(1)	(2)	(3)
VARIABLES	East	Mid	West
did	0.0102**	0.0032**	0.0002
	(0.0043)	(0.0013)	(0.0043)
Controls	Yes	Yes	Yes
ID FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	104	64	72
Adj. R-squared	0.921	0.939	0.907

5.2 Industry type regression

This study adopts the factor intensity classification criteria proposed by Zhang Yizhen and Cao Weidong (Zhang Yizhen 2020), categorizing the 17 analyzed manufacturing industries into four primary groups: resource-intensive, capital-intensive, labor-intensive, and technology-intensive. The specific industry types, along with their corresponding codes, are detailed in Table 8. Table 9 presents the estimated results of the impact of the CCS on the resilience of these different types of manufacturing industries, taking into account various regional conditions and implementation periods. This study emphasizes the distinct characteristics between industries by focusing on inter-industry differences at the industry level in its analysis. Consequently, it does not account for regional fixed effects and year fixed effects. This approach is intentional to circumvent the potential dilution effect of control variables on inter-industry differences, thereby enabling a clearer identification of the heterogeneity performance and its intrinsic mechanism among diverse industries. The subsequent analysis bolsters the reliability of the conclusions through the implementation of grouped regression and robustness tests. Empirical analysis reveals significant differences in the effects of the CCS on these industries: the coefficient estimate for resource-intensive manufacturing is 0.0016, with a statistical test passed at the 10% significance level; the coefficient estimate for capital-intensive manufacturing is 0.0020, passing the statistical test at the 5% significance level; the coefficient estimate for labor-intensive manufacturing is 0.0012 but fails to pass the significance test; and the coefficient estimate for technology-intensive manufacturing is 0.0019, with a statistical test passed at the 1% significance level.

Empirical results indicate that the CCS significantly positively impacts resource-intensive, capital-intensive, and technology-intensive manufacturing industries, albeit at varying degrees. Notably, the policy's impact on the technology-intensive manufacturing industry is the most pronounced, followed by capital-intensive and resource-intensive manufacturing industries. However, its impact on the labor-intensive manufacturing industry has not withstood the significance test. This differential impact can be attributed to several factors. Firstly, in line with the strategic imperatives outlined in the 20th National Congress of the Communist Party of China's report—which emphasize enhancing the resilience and security of industrial chains and supply chains and focusing on "neck-carding" technology breakthroughs—the technology-intensive manufacturing sector has emerged as a focal point for implementing the CCS. Unlike traditional consumer goods manufacturing, advanced manufacturing sectors such as intelligent equipment manufacturing, advanced materials, information technology, biomedicine, and integrated circuits exhibit dual-intensive characteristics of capital and technology. Their competitive edge largely hinges on their technological innovation capabilities and R&D investment intensity. Such inherent industry traits render the CCS instrumental in fostering industrial chain collaborative innovation and overcoming critical core technology impediments. Secondly, for resource-intensive and capital-intensive manufacturing industries, China boasts robust international competitiveness in areas like green petrochemicals, new building materials, and new energy. Additionally, these sectors have relatively comprehensive industrial chain systems. The CCS plays a pivotal role in leveraging these strengths, amplifying its effectiveness in these domains.

The CCS markedly augments the stability and resilience of the industrial chain, primarily through the optimization of resource distribution, facilitation of technological collaboration, and fortification of the linkage between upstream and downstream industries. This has a noteworthy promotional impact on these two categories of industries. Labor-intensive manufacturing industries, however, are more dependent on market mechanisms and labor cost benefits. Since the focus of the CCS is on technological upgradation, resource integration, and industrial chain extension, it diverges to some extent from the core requirements of labor-intensive industries. Consequently, while the CCS policy does exert a certain amount of promotion on this type of industry, its effect has not achieved statistical significance. Thus, research hypothesis 2 is confirmed.

Table 8 Manufacturing industries classified by factor intensity

Type of industry	Industries and codes included
Resource-intensive	C30 Non-metallic mineral products； C33 Metal products； C25 Petroleum, coke products and nuclear fuel processing products
Capital-intensive	C26 Chemical products； C13-C15 Food and tobacco； C31 Metal smelting and calendering products； C20-C21 Wood processing products and furniture
Labor-intensive	C13-C15 Food and tobacco; C17 Textiles； C18 Textiles, Clothing, Footwear, Leather, Down and Their Products； C22-C23 Papermaking, Printing, Educational and Sports Supplies
Technology-intensive	C40 Instrumentation； C36 Transportation equipment； C38 Electrical machinery and equipment； C34 General purpose equipment； C35 Special equipment； C39 Communication equipment, computers and other electronic equipment

Table 9 Results of industry heterogeneity analysis

	Resource-intensive	Capital-intensive	Labor-intensive	Technology-intensive
did	0.0016*	0.0020**	0.0012	0.0019***
	(0.0010)	(0.0009)	(0.0009)	(0.0007)
Controls	Yes	Yes	Yes	Yes
Observations	51	665	497	986
Adj. R-squared	0.5832	0.5689	0.6076	0.5813

5.3 Industry type regression

To further test the robustness of industry heterogeneity results, this paper adds region and year fixed effects to the baseline model and re-estimates regression results for different industries. The relevant findings are shown in Table

10 .On the basis of the previous industry heterogeneity results, this paper further controls regional and time fixed effects to conduct a robustness test on industry heterogeneity. The results show that after strictly controlling cross-regional development gaps and common temporal shocks, the estimated coefficient directions of the chain chief policy remain consistent across manufacturing sectors, but inter-industry differences have statistically significant attenuation. This shows that the observed industrial differences in the baseline regression are partly affected by factors such as regional industrial foundations, resource endowments, and macroeconomic environments. In addition, it may be related to the short implementation period of the chain chief policy during our research window. As an institutional arrangement centered on organizational coordination and industrial chain governance, its policy effect has certain lag and cumulative characteristics, which had not yet produced stable and significant differentiation among industries within the sample period. Moreover, after adding region and year fixed effects and provincial-level clustering robust inference, the effective variance identifying industry differences is further reduced, thus weakening the statistical significance of industry heterogeneity results.

In conclusion, the empirical results of this paper show that the chain liability system policy has a differentiated impact on industries based on practical foundations. However, after strictly controlling for regional and time factors, the statistical significance of differences between industries is reduced. This finding shows that the industrial heterogeneity of the chain liability system policy has certain stage characteristics and conditional attributes. Overall, Hypothesis 2 obtains support under baseline specification, while robustness tests further clarify its applicable boundaries.

Table 10 Industry Heterogeneity Test Controlling for Regional and Year Fixed Effects

	(1)	(2)	(3)	(4)
	Resource-intensive	Capital-intensive	Labor-intensive	Technology-intensive
did	0.00177	0.00218	0.00181	0.00184
	(0.00180)	(0.00219)	(0.00187)	(0.00178)
Controls	Yes	Yes	Yes	Yes
Id FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	317	207	211	624
Adj. R-squared	0.963	0.959	0.960	0.964

Note: Because of the difference in the number of firms and data availability across industries during the sample period, the effective sample sizes for industry-specific regressions vary accordingly. After controlling for region and year fixed effects, some industry samples change due to absorption by the fixed effects.

6. Impact path analysis

6.1 Industrial synergy and agglomeration

The degree of regional industrial agglomeration serves as a critical metric for assessing the comprehensive coordination capabilities of regional industries. This agglomeration effect is manifested not only in the spatial clustering of identical or related industries but also in the collaborative integration and value redefinition across the upstream, midstream, and downstream segments of the industrial chain. A pronounced level of industrial agglomeration can markedly enhance the scientific rigor of regional industrial planning, optimize resource distribution, and bolster market mechanisms. Consequently, this strengthens the overarching coordination capacity of the regional industrial system. In light of this, the degree of industrial agglomeration warrants consideration as a pivotal indicator in evaluating the overall coordination efficiency of regional industries. Building upon the research methodologies of

Ji Yujun (Yaxin 2023), this paper employs location entropy as a means to gauge the agglomeration intensity of local manufacturing industries, with the specific measurement methodology delineated in Eq. (4):

$$magg_{ijt} = \frac{e_{ijt}/\sum_i e_{ijt}}{\sum_j e_{ijt}/\sum_i \sum_j e_{ijt}} \tag{4}$$

In this study, $magg_{ijt}$ denotes the location entropy of the manufacturing industry j in province i during period t, categorized according to the "National Economic Industry Classification" (GB/T4754-2017) standard. e_{ijt} signifies the employment figure for the manufacturing industry in province i during period t; $\sum_i e_{ijt}$ represents the total employment number in the manufacturing sector nationwide during period t; $\sum_j e_{ijt}$ denotes the cumulative employment figure in province i during period t; and $\sum_i \sum_j e_{ijt}$ indicates the overall employment figure across the country during period t. A larger value of $magg_{ijt}$ suggests a higher degree of agglomeration within the manufacturing industry, while a smaller value indicates a more dispersed distribution. Moreover, in line with the approach of smoothing indicators adopted by Zhou Yuding and others (Yuding, Xiaosong et al. 2023), the computed manufacturing industrial agglomeration index undergoes discretization. Specifically, $magg_{ijt}$ is segmented into 10 groups from high to low, aligning with dummy variables 1 to 10, and denoted as $magg1_{ijt}$. It is also divided into 5 groups from high to low, corresponding to dummy variables 1 to 5, and labeled as $magg2_{ijt}$, to ensure result robustness. Table 11 presents the regression outcomes based on the calculated industrial agglomeration index, revealing that the coefficient estimates for the interaction terms did×magg, did×magg1, and did×magg2 are significantly positive at the 1% level. This analysis further confirms that the CCS markedly bolsters the resilience of the manufacturing industrial chain by fostering industrial synergy agglomeration, refining inter-industry coordination mechanisms, and enhancing risk resistance.

Table 11 Test Results of the Industrial Synergistic Agglomeration Mechanism

	(1)	(2)	(3)
VARIABLES	PR	PR	PR
did×magg	0.0088**		
	(0.0037)		
did×magg1		0.0012**	
		(0.0006)	
did×magg2			0.0024**
			(0.0010)
Controls	Yes	Yes	Yes
ID FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	240	240	240
Adj. R-squared	0.895	0.893	0.893

6.2 Regional innovation

The CCS, an innovative industrial governance mechanism, effectively transforms the fragmented competitive landscape of traditional industrial organizations by establishing a systematic framework for industrial chain coordination. This promotes the formation and collaborative evolution of industrial clusters. The system markedly improves resource allocation efficiency and collaboration between regions and industries. It also provides innovation entities with more certain expectations of returns on innovation, thereby encouraging them to increase their investment in innovation. This institutional innovation optimizes not only the structure of industrial organizations but also contributes to the sustainable momentum of high-quality regional industrial development. Based on this analysis, the paper selects invention patents (LN invent), utility model patents (LN use), and design patents (LN perform) from each province as core indicators of regional innovation capability. These are all processed by adding 1 and then taking the natural logarithm. To enhance the comparability of these indicators, the study employs the calculation method, characterizing the level of regional technological innovation by the ratio of patent grants to the permanent population in the region. Regression analysis results in Table 12 reveal that the coefficients of each interaction term are significant at the 1% statistical level. These empirical results suggest that regional innovation R&D investment plays a key role in promoting regional collaborative development and enhancing industrial chain resilience under the CCS. This validates the establishment of research hypothesis 3.

Table 12 Test Results of Regional Innovation Mechanism

	(1)	(2)	(3)	(4)
VARIABLES	PR	PR	PR	PR
did×Lninvent	0.0008*			
	(0.0004)			
did×Lnuse		0.0007*		
		(0.0004)		
did×Lnperform			0.0008*	
			(0.0004)	
did×tech-innovation				0.0004***
				(0.0001)
Controls	Yes	Yes	Yes	Yes
Id FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	240	240	240	240
Adj. R-squared	0.891	0.891	0.891	0.898

6.3 Regional business environment

The CCS focuses on the leading industries and key enterprises that drive local economic development. It employs government coordination to facilitate the synchronization of activities across various nodes of the industrial chain. This system leverages the administrative functions of local governments, harnessing their coordinating capabilities to guide the market within critical industrial domains. Consequently, it fosters stability and growth throughout the industrial chain. A key indicator of a robust business environment is the effective coordination between government and market relations. Market intermediary organizations are instrumental in linking and coordinating the functions of the industrial chain. Their developmental level significantly impacts the industrial chain's adaptability to economic fluctuations. A well-developed intermediary organization system can assist entities at different nodes of the industrial chain in timely sensing market changes and implementing collaborative response measures. This is achieved through mechanisms such as information transmission, resource allocation, and risk sharing, effectively maintaining the dynamic stability of the industrial chain. Concurrently, the legal environment, a fundamental institutional arrangement for regulating market economy operations, provides institutional support for optimizing the business environment.

The enhancement of market intermediary organizations and the refinement of the legal system environment are crucial aspects of a conducive business environment. This paper, in accordance with the research methodology of Wang (WANG Na 2024), employs data from the "China Provincial Business Environment Evaluation Database 2023", a collaborative project by Peking University and Wuhan University. It uses scores for Government and Market Relations (GMR), Intermediary Organization Development and Legal Scores (IOD), and Fan Gang's Marketization Index (MI) as key indicators of regional business environments. Table 13 presents regression results using these three indicators as mechanism variables. The results demonstrate that the coefficient estimates for did×GMR, did×IODLS, and did×MI all pass the significance test at the 1% level. The findings suggest that the CCS systematically optimizes the business environment by establishing an institutional support system encompassing three dimensions: improved efficiency of government services, standardized market order, and strengthened legal protection. This institutional framework effectively reduces the transaction costs associated with industrial chain operations, significantly enhancing the stability and risk resistance of the industrial chain. It achieves this by offering efficient administrative services, maintaining a competitive market environment, and providing comprehensive legal protection mechanisms, thereby empirically validating Research Hypothesis 4.

Table 13 Test Results of the Business Environment Mechanism

	(1)	(2)	(3)
VARIABLES	PR	PR	PR
did×GMR	0.0009*		
	(0.0004)		
did×IOD		0.0012*	
		(0.0006)	
did×MI			0.0007*
			(0.0004)
Controls	Yes	Yes	Yes
Id FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	240	240	240
Adj. R-squared	0.892	0.891	0.892

6.4 Efficiency of resource allocation

The efficiency of resource allocation forms the backbone of resilience within the manufacturing industrial chain. By optimizing the flow of factors, achieving precise supply-demand matching, and facilitating rapid response to changes, it markedly boosts the industrial chain's resistance to impacts, adaptability, and transformative capabilities. The CCS constructs a novel paradigm for resource allocation, one driven by both "government-market". This approach dismantles departmental barriers via administrative coordination, finely tunes the supply-demand equation for factors, dynamically optimizes the industrial ecosystem, and substantially enhances the efficiency of resource allocation across the entire industrial chain. This paper adopts the research references of Wang Hongming (Wang Hongming 2022), utilizing the R&D capital misallocation index, R&D personnel misallocation index, and innovation resource misallocation index as proxies for measuring regional resource allocation efficiency. The formulas for calculating the R&D capital misallocation index and R&D personnel misallocation index are as follows:

$$\hat{\gamma}_{ki} = \frac{1}{1+\tau_{ki}}, \quad \hat{\gamma}_{Li} = \frac{1}{1+\tau_{Li}} \tag{5}$$

$$\hat{\gamma}_{Ki} = \frac{\left(\frac{K_i}{K}\right)}{\left(\frac{S_i\beta_{Ki}}{\beta_K}\right)}, \quad \hat{\gamma}_{Li} = \frac{\left(\frac{L_i}{L}\right)}{\left(\frac{S_i\beta_{Li}}{\beta_L}\right)} \tag{6}$$

In this equation, τ_{ki} denotes the R&D capital misallocation index, while τ_{Li} signifies the R&D personnel misallocation index. In equation (5), $\hat{\gamma}_{ki}$ and $\hat{\gamma}_{Li}$ are the absolute distortion coefficients of R&D factor prices, which are typically substituted with relative price distortion coefficients. The variables ki and Li represent the stock of R&D capital and the full-time equivalent of R&D personnel in region i respectively. S_i denotes the proportion of innovative output in region i, while β_{Ki} and β_{Li} represent the output elasticities of R&D capital and personnel in the same region, respectively. The measurement of innovative output is based on the number of patent applications, and the input of R&D personnel and capital are both sourced from the "China Science and Technology Statistical Yearbook".

The examination of the efficiency mechanism of resource allocation, as presented in Table 14, reveals significant findings. The interaction term between the CCS and the R&D personnel mismatch index is significant at the 1% level, while the interaction term with the R&D capital mismatch index is significant at the 5% level. These results empirically support the notion that the CCS effectively mitigates regional innovation resource mismatches by enhancing the efficiency of R&D element allocation. However, the coefficient of the interaction term between the CCS and the innovation resource mismatch index, though positive, is not statistically significant. This could be attributed to the hierarchical and temporal aspects of resource allocation. In terms of structure, innovation resource allocation, encompassing elements such as R&D personnel, capital, and technical equipment, is inherently more complex than single-element allocation. This complexity might lead to organizational friction during cross-element collaboration. Temporally, there exists an asymmetry in the recombination of innovation elements. While specific adjustments like R&D personnel mobility and capital modifications can be rapid, comprehensive innovation resource optimization necessitates an extended policy digestion period. This duration makes it challenging for short-term observation windows to discern policy impacts. In conclusion, the CCS refines element allocation via administrative coordination, appropriately augmenting and fortifying chains. This enhances the resilience of manufacturing industrial chains through superior resource integration and dynamic adjustment capabilities, thereby confirming the validity of research hypothesis 5.

Table 14 Test Results of Resource Allocation Efficiency Mechanism

	(1)	(2)	(3)
VARIABLES	PR	PR	PR
did×capital	0.0080*		
	(0.0041)		

did×staff		0.0070	
		(0.0154)	
did×resources			0.0123*
			(0.0068)
Controls	Yes	Yes	Yes
ID FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	240	240	240
Adj. R-squared	0.888	0.886	0.887

7. Discussion

In the context of global industrial chain restructuring and heightened external uncertainties, bolstering the resilience of China's manufacturing industry chains through institutional innovation has emerged as a pivotal strategy for promoting high-quality development and ensuring economic security. This study considers the "CCS" policy as a quasi-natural experiment, offering a comprehensive examination of its effects on the resilience of manufacturing supply chains and elucidating the mechanisms at play, using provincial-level macroeconomic data. The empirical results suggest that the CCS generally enhances regional manufacturing supply chain resilience, with notable variations across regions and industries. A deeper mechanistic exploration reveals that this policy operates not through a singular channel but offers multifaceted support to manufacturing supply chain resilience by fostering collaborative industrial agglomeration, refining the business environment, and boosting resource allocation efficiency.

Drawing on existing research, scholars have systematically investigated the policy effects of the CCS across multiple levels. At the micro level, studies have examined its impacts on enterprise technological innovation (WANG Na 2024, Wanshan 2024), total factor productivity (Yuding, Xiaosong et al. 2023, Xinrui 2025), financing costs (Chen Yunsen 2025), and economic and environmental performance (Yuding 2025, Zeng Huixiang 2025). These studies indicate that the CCS positively influences corporate behavior and performance by enhancing the driving role of leading enterprises and improving resource allocation for firms(LIU Huiqin 2025). At the meso- and macro-levels, the literature has broadened its analytical perspective to encompass industrial-innovation chain coordination (Shenghui 2025, XiaoYunmei 2025, Yang Jin 2025), the deep integration of science and technology innovation (Chenzhao 2025) with industrial innovation (Tang Yuehuan 2025), the modernization of industrial chains (Qi 2023), and the high-quality development of regions and urban agglomerations (Feng 2025, LIU Huiqin 2025, Ze, Yan et al. 2025). This suggests that the CCS, as an industrial chain collaborative governance mechanism, significantly contributes to promoting industrial agglomeration, facilitating innovation factor mobility, and guiding green transitions. In terms of operational mechanisms, existing research has comprehensively analyzed policy transmission pathways through various dimensions, including industrial agglomeration effects (Yang Jin 2025), innovation spillover effects (Tang Yuehuan 2025, Yang Jin 2025), government coordination and policy support effects (FAN Hejuna 2025), and improvements in factor allocation efficiency (Huiqin, Menghui et al. 2025).

However, overall, the existing studies have mostly regarded the CCS as a policy tool to promote economic growth, innovation upgrading or green transformation. The dependent variables of these studies are mostly concentrated on specific development results such as enterprise performance, industrial development quality or environmental performance, but pay insufficient attention to the stability, resilience and structural evolution ability of the industrial chain itself under uncertain shocks. Although supply chain resilience has gradually become an important research topic, there is still a lack of systematic investigation into the integration of China's characteristic industrial chain governance mechanism and manufacturing industrial chain resilience within the same analytical framework from the operational logic of the industrial chain system. Based on the foundational and strategic position of the manufacturing industry in the national economic system, this paper integrates the CCS with the resilience of the manufacturing industrial chain. Focusing on analyzing the coordination mechanism between the CCS and the stability, restoration ability and evolution ability of the manufacturing industrial chain. From the perspective of institutional governance, this study provides new empirical evidence and theoretical contributions for understanding the formation mechanism of industrial chain resilience.

The CCS's effectiveness in bolstering the resilience of manufacturing industrial chains is rooted in its high functional alignment with the concept of manufacturing industrial chain resilience. This resilience underscores the comprehensive ability to sustain stable operations amidst external shocks, facilitate swift recovery, and stimulate structural evolution and upgrading. The CCS, which focuses on core missions such as "stabilizing chains, supplementing missing links, extending industrial chains, and strengthening key nodes", is fundamentally designed to foster holistic security and long-term resilience of manufacturing industrial chains. By instituting a collaborative governance mechanism between government-appointed chain chiefs and enterprise-led chain masters, this system enhances the systematic coordination capacity for manufacturing industrial chain operations at an institutional level. It effectively mitigates market failures in cross-departmental coordination, information integration, and factor allocation, thereby providing crucial institutional support for maintaining industrial chain stability. In its practical application, the CCS augments both connectivity strength and substitution elasticity among key nodes within industrial chains. This is achieved by fostering collaborative agglomeration in manufacturing industries, diminishing institutional transaction costs, and enhancing factor allocation efficiency. As a result, this mechanism bolsters the shock-resistant capacity and restorative capability of industrial chains when confronted with external disturbances. Concurrently, by directing resource concentration towards critical and vulnerable links, the CCS paves the way for structural adjustment and functional reconstruction of manufacturing industrial chains post-shock. This facilitates a shift from passive repair to proactive evolution. Therefore, the resilience-enhancing effect of the CCS on manufacturing industrial chains extends beyond temporary improvement stemming from short-term administrative intervention. Instead, it represents an institutional embedding that yields multidimensional structural enhancement across stability, resilience, and evolutionary capacity.

Although this paper provides empirical evidence at the macro level to understand the industrial chain resilience effect of the CCS policy, it still has certain limitations. Firstly, the analysis is mainly based on provincial-level data, making it difficult to fully characterize the specific operational mechanisms of the CCS at a more micro level. Especially against the background of significant differences in institutional environments and industrial foundations among regions, the existing analytical framework cannot fully reveal how governments and enterprises interact and coordinate around the industrial chain. Secondly, this study uses the PR index as a proxy variable for structural dimensions when measuring resilience, without further incorporating multidimensional indicators such as recovery speed and risk diffusion rate that capture high-frequency dynamic processes. Future research can explore an indicator system for multidimensional industrial chain resilience based on higher frequency and finer-grained data. By employing multi-algorithm comparisons and sensitivity analyses to test the robustness of conclusions, combined with enterprise-level data or typical regional cases, future studies could further dissect the operational mechanisms and differentiated effects of the CCS across different industrial chains and regions from a micro perspective, thereby achieving a more comprehensive understanding of the mechanism by which this institutional innovation enhances the resilience of manufacturing industrial chains.

8. Conclusion

The empirical analysis suggests that the CCS notably augments the resilience of the manufacturing industrial chain within the region where it is enacted. This conclusion holds true even after conducting trend tests, placebo tests, and various robustness checks. Further examination indicates that the policy's effects exhibit noticeable regional and industrial heterogeneity: Regionally, both the eastern and central regions demonstrate a significant enhancement, whereas the western region's improvement has not yet achieved statistical significance. In terms of industry, technology-intensive sectors benefit the most, followed by capital-intensive and resource-intensive industries, with labor-intensive industries showing comparatively limited improvements. In-depth research reveals that the CCS primarily influences the resilience of the manufacturing industrial chain through mechanisms such as fostering industrial agglomeration innovation, optimizing regional business environments, and enhancing resource allocation efficiency.

The research findings suggest several policy recommendations to bolster the resilience of the manufacturing industrial chain. Firstly, on a regional scale, the eastern region should capitalize on its financial and technological strengths by fortifying the development of innovation consortia. The central region needs to enhance relevant supporting facilities and set up a mechanism for cross-regional industrial transfer docking, while the western region should prioritize infrastructure development and factor security, with a focus on fostering characteristic industrial chains. Secondly, from an industry perspective, technology-intensive industries should concentrate on establishing a collaborative innovation system encompassing production, learning, research, and application to achieve breakthroughs in key core technologies. Capital-intensive industries need to finetune their financing services and capacity coordination mechanisms. Labor-intensive industries must encourage intelligent transformation and skill development, whereas resource-intensive industries should underscore the importance of green technological innovation and circular model application. By implementing a nuanced policy support system for the industrial chain chief, and augmenting the synergistic coupling effect of each link in the chain, we can expedite the evolution and upgrading of the manufacturing industrial chain along high-end, intelligent, and sustainable trajectories.

In examining the influencing mechanisms, several strategies stand out. Firstly, industrial synergy and agglomeration are promoted by optimizing regional industrial layouts and fostering spatial organic connections and functional complementarity among enterprises in the industrial chain's upstream and downstream segments. This approach leverages scale effects and cluster advantages. Secondly, the business environment is continuously refined through the "delegation-regulation-service" reform, streamlining of administrative approval processes, and reduction of institutional transaction costs for enterprises, thereby cultivating a more supportive institutional environment for industrial chain development. Thirdly, innovation incentive mechanisms are strengthened by establishing dedicated innovation funds for the industrial chain, prioritizing key core technology challenges, and bolstering the industrial chain's independent innovation capability. Lastly, factor market reforms are enhanced by creating comprehensive talent mobility mechanisms, multi-tiered capital market systems, and data element trading platforms. These efforts aim to optimize the allocation and efficient movement of various production factors within the industrial chain. Collectively, these measures constitute a cohesive policy support system encompassing "industrial synergy, environment optimization, innovation drive, and factor guarantee," thereby elevating the modernization and risk resilience of the industrial chain.

While this study has made certain theoretical advancements, it is not without limitations. Primarily, the research relies on a provincial-level analytical framework and does not explore policy effect heterogeneity at more granular levels, such as city or county scales. Future research could benefit from refining these analysis units to improve the precision of its conclusions. Additionally, future work will aim to construct a more comprehensive indicator system to assess the resilience of the manufacturing industrial chain.

9. Declaration of generative AI and AI-assisted technologies in the writing process.

During the preparation of this work the authors used ChatGPT in order to improve the readability and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

10. Competing interests

The authors declare no competing interests.

11. Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

12. Informed consent

This article does not contain any studies with human participants performed by any of the authors.

13. Data availability

We have provided the raw data for all variables, as well as the results of certain variables that have been calculated and processed. All the data has been consolidated and uploaded as part of the manuscript attachments. The variables constructed from publicly available sources are based on original data obtained from the official website of the National Bureau of Statistics of China ([https://www.stats.gov.cn/]) and other relevant governmental statistical publications.

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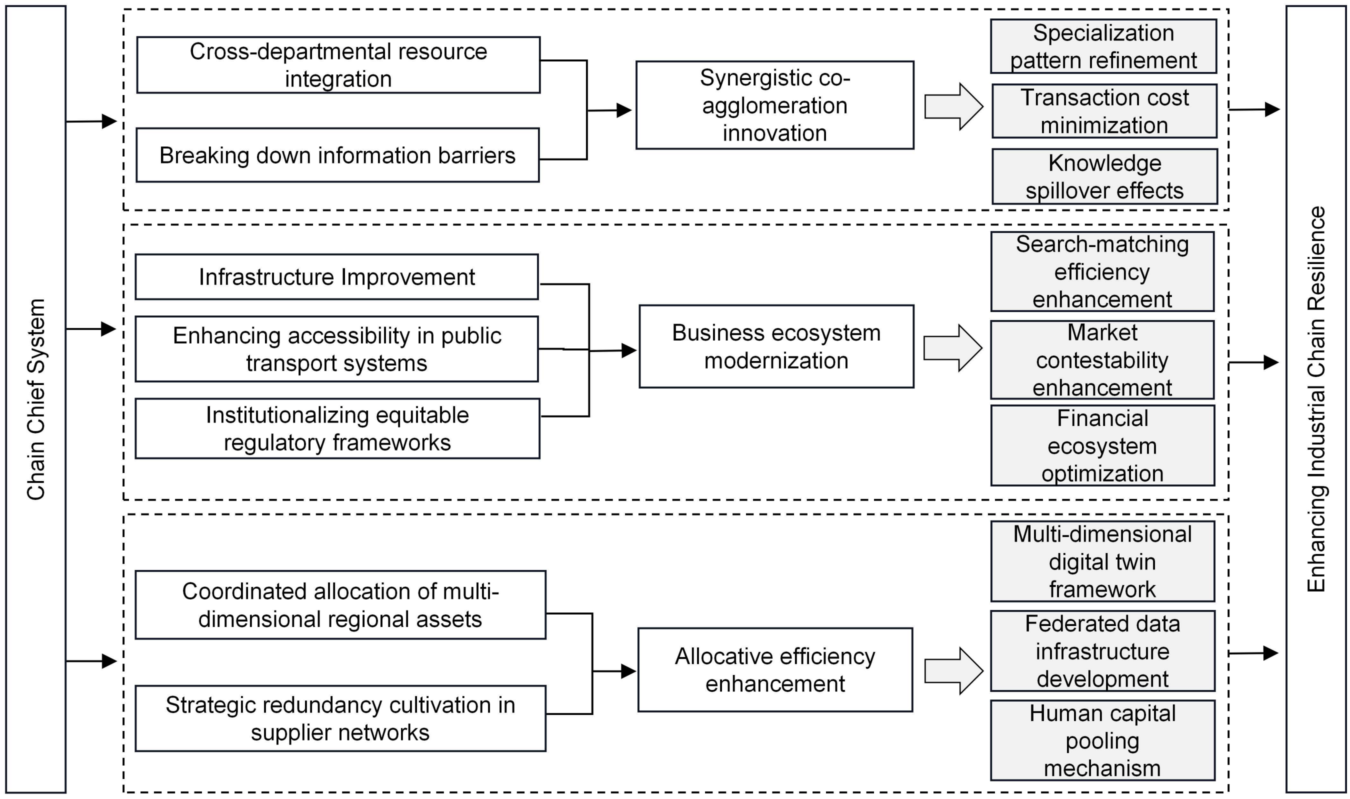
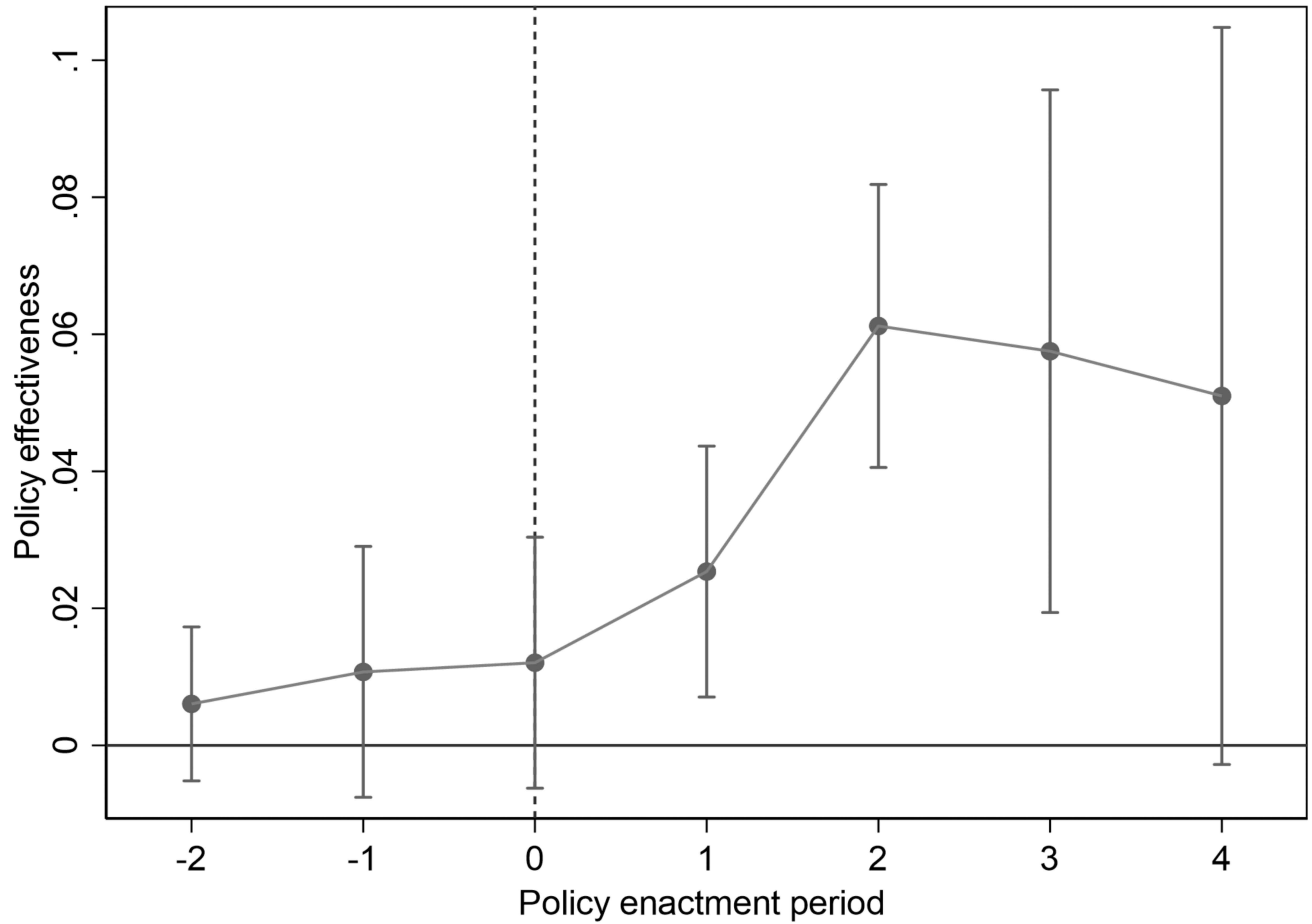
Figure 1 Presents the path diagram illustrating the effects of the CCS on the resilience of the manufacturing industrial chain

Figure 2 Dynamic effects of policies

Figure 3 Individual placebo test result

In Figure 3, • denotes the p-value, and — represents the kdensity beta.


Chain Chief System
Cross-departmental resource integration
Breaking down information barriers
Synergistic co-agglomeration innovation
Specialization pattern refinement
Transaction cost minimization
Knowledge spillover effects
Infrastructure Improvement
Enhancing accessibility in public transport systems
Institutionalizing equitable regulatory frameworks
Business ecosystem modernization
Search-matching efficiency enhancement
Market contestability enhancement
Financial ecosystem optimization
Coordinated allocation of multi-dimensional regional assets
Strategic redundancy cultivation in supplier networks
Allocative efficiency enhancement
Multi-dimensional digital twin framework
Federated data infrastructure development
Human capital pooling mechanism
Enhancing Industrial Chain Resilience


Policy effectiveness
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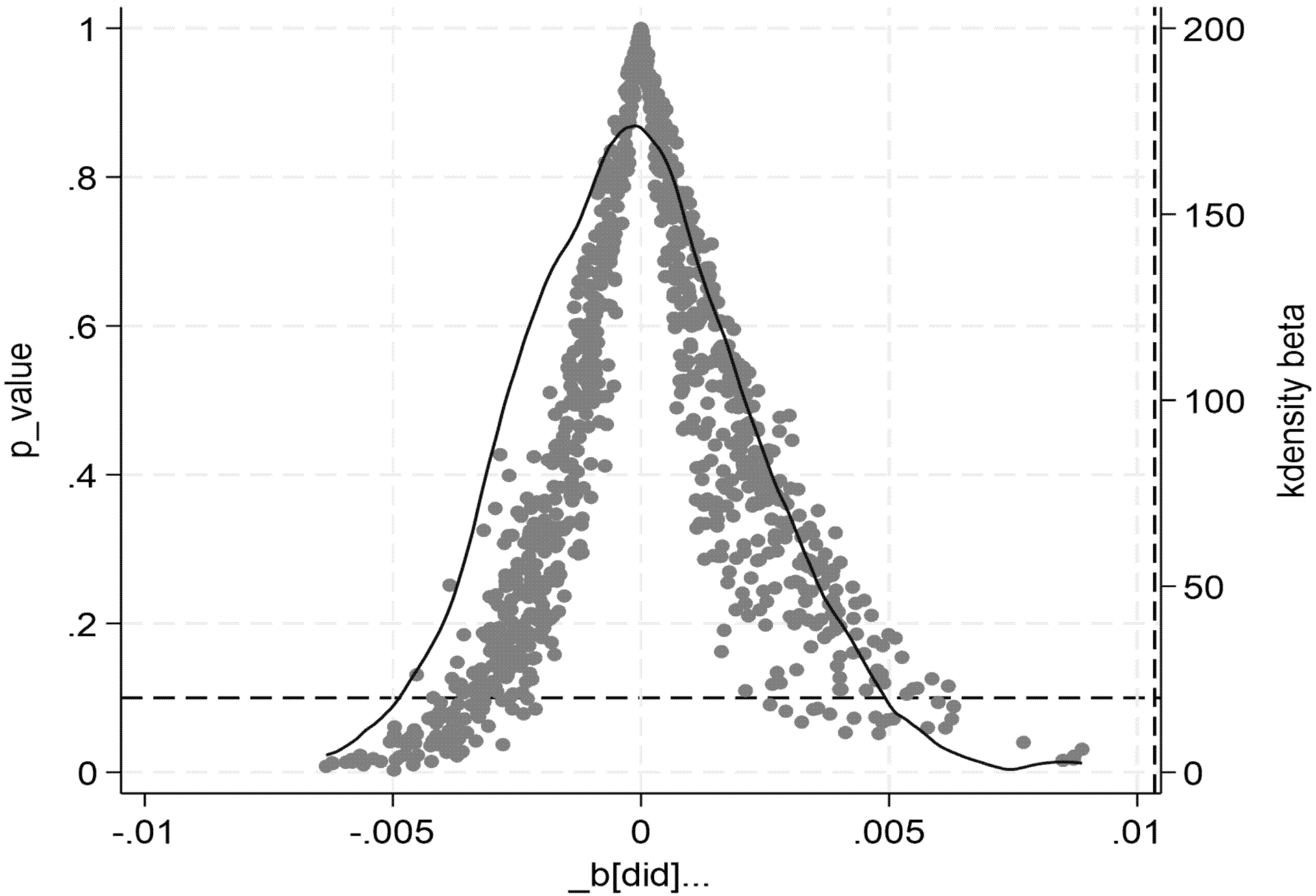
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