

Article

Data-Driven Systemic Governance for Smart-City–Regional Emergency Collaboration: Evidence from China’s National Big Data Comprehensive Pilot Zones

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Abstract

Smart-city governance increasingly relies on data infrastructures to connect public agencies, digital platforms, and urban services; however, complex emergencies continue to expose fragmentation in information sharing, administrative responsibilities, and cross-boundary coordination. A key unresolved question is whether data-driven policy experimentation can strengthen the institutional foundations of emergency collaboration. In this study, we examine China’s National Big Data Comprehensive Pilot Zones as a systemic governance intervention and apply a multi-period difference-in-differences model to estimate the effect of pilot-zone construction on the policy-text-based institutionalization of emergency collaboration, using provincial panel data for 30 Chinese provinces from 2010 to 2022. The results show that pilot-zone construction significantly strengthens institutionalized emergency collaboration in provincial policy systems. Mechanism tests provide evidence consistent with two complementary pathways: emergency-related technological innovation, measured by granted patents screened through IPC/CPC classifications and title–abstract keywords, supports task-specific capacities such as risk sensing, early warning, emergency communication, command support, and resource allocation; digital government strengthens administrative interoperability, data sharing, platform-based coordination, and standardized interdepartmental procedures. Heterogeneity analyses show stronger effects in eastern, middle-income, and severely aging regions, suggesting that policy effectiveness depends on implementation capacity, absorptive capacity, and emergency-service demand. This study contributes to systems governance and smart-city research by showing how data-driven policy experimentation can shape the formal institutionalization of emergency collaboration. The findings should be interpreted as evidence of institutionalized policy attention and formal collaborative arrangements rather than direct evidence of field-level emergency response performance.



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Keywords: systemic governance; smart cities; institutionalized emergency collaboration; National Big Data Comprehensive Pilot Zone; emergency-related technological innovation; digital government

1. Introduction

Smart cities are increasingly shaped by the interaction between data infrastructures, digital platforms, public institutions, and urban services. Digital transformation is reshaping public governance systems by altering how information is generated, circulated,

interpreted, and translated into collective action. As sensors, big data platforms, artificial intelligence, cloud computing, and integrated government-service systems become embedded in urban governance, cities are no longer governed only through administrative hierarchy or sectoral policy instruments; instead, they increasingly operate as complex socio-technical systems in which information flows, organizational routines, infrastructure networks, and citizen needs are closely interconnected [1]. This transformation is particularly important in emergency management, where disasters and public crises are increasingly characterized by complexity, uncertainty, cascading effects, and interdependence across administrative, infrastructural, and social subsystems; therefore, emergency collaboration is not merely an administrative coordination issue, but a systemic governance problem embedded in complex socio-technical systems. As public agencies, infrastructure operators, technology providers, communities, and social organizations respond to rapidly evolving risks, effective emergency governance depends on whether information, resources, responsibilities, and decision-making processes can be connected across organizational and sectoral boundaries [2]. However, traditional emergency-management systems often suffer from information silos, fragmented responsibilities, delayed feedback, and inefficient resource allocation, which constrain their capacity to address compound and rapidly changing risks [3].

Emergency governance in complex urban and city–regional systems depends on whether public agencies can transform dispersed information into coordinated action. Data elements provide a new possibility for addressing these systemic coordination problems: big data, artificial intelligence, the Internet of Things, remote sensing, and digital platforms can expand the sensing, analytical, and decision-support capacities of emergency-governance systems [4]. For example, the failure of data-sharing mechanisms among meteorological, water conservancy, transportation, and other departments was one of the important factors behind delayed disaster assessment and disordered response during the “7·20” extreme rainstorm disaster in Zhengzhou, China [5], illustrating that emergency collaboration depends not only on hierarchical command, but also on the timely circulation and institutionalized use of cross-departmental data. Data-driven technologies can support real-time risk perception, prediction of disaster evolution, public opinion monitoring, resource demand estimation, and dynamic allocation of emergency supplies [6,7]; more importantly, data can become a governance infrastructure that enables different departments to develop a shared situational awareness and coordinate actions under a common information environment. From a systems perspective, the central issue is not whether digital technologies are available, but whether data infrastructures, organizational routines, and institutional rules can be coupled to generate collaborative capacity.

Data-driven governance provides a potential pathway for addressing these systemic coordination challenges, but digital technologies do not automatically generate collaborative governance capacity. From a systemic perspective, data become valuable for emergency governance only when they are embedded in institutional routines, administrative processes, and cross-boundary coordination rules; in other words, the governance value of data infrastructures depends on whether they can reconfigure the relationships among public agencies, digital platforms, infrastructure operators, communities, and other actors. This issue is central to the governance of smart cities, which are not simply technology-intensive spaces but evolving socio-technical arrangements in which data, institutions, infrastructures, and public value are continuously co-produced.

China’s National Big Data Comprehensive Pilot Zones provide a valuable empirical setting for examining this issue. Since 2015, China has promoted the development of big data as a national strategy and used pilot zones as policy laboratories for exploring data resource integration, data sharing, digital infrastructure construction, big data industrial

development, and institutional innovation. Guizhou was approved as the first national pilot zone, and subsequent zones were established in regions including Beijing–Tianjin–Hebei, the Pearl River Delta, Shanghai, Henan, Chongqing, Shenyang, and Inner Mongolia. These pilot zones are not only technology-oriented policy instruments, but also institutional experiments intended to promote data circulation, interdepartmental coordination, and digital governance capacity, therefore providing a quasi-natural experiment for evaluating whether data-driven policy experimentation can enhance emergency collaboration and through which mechanisms such effects occur.

Existing studies on National Big Data Comprehensive Pilot Zones have produced important findings, but their analytical focus remains uneven. A large body of research has examined the economic and technological consequences of pilot-zone policies, including total factor productivity, high-quality economic development, enterprise innovation, digital industrialization, industrial integration, and technology market development [8–11]. Other studies have extended the discussion to green transformation, carbon reduction, air quality improvement, employment, and resource allocation efficiency [12–15]. These studies demonstrate that big data pilot zones can generate broad developmental effects by improving digital infrastructure and facilitating the circulation of data elements. However, the public safety implications of such policies remain insufficiently examined; in particular, limited attention has been paid to whether and how big data pilot zones reshape emergency collaboration, even though emergency management is a typical field in which cross-boundary information sharing, resource integration, and rapid coordination are essential. More importantly, their implications for systemic governance in smart-city–regional settings remain underexplored.

Two gaps are especially important: First, the relationship between data elements and emergency collaboration remains insufficiently theorized and causally tested. Although emergency-management studies have emphasized information sharing, digital platforms, and intelligent decision support in crisis response [16–19], they often focus on specific technologies or single emergency scenarios; less is known about whether a broader data governance policy can systematically enhance emergency collaboration at the regional level. This gap is especially relevant to smart-city research because emergency collaboration depends on how data infrastructures, administrative organizations, and urban service systems interact under conditions of complexity and uncertainty. Second, the mechanisms linking data-driven policy experimentation and emergency collaboration remain unclear. Existing studies often adopt a technology-centered explanation, assuming that digital technologies directly improve governance performance; however, in complex governance systems, technological capacity generates collaborative value only when embedded in institutional arrangements, organizational processes, and interdepartmental rules. Therefore, technological innovation and digital government may constitute two complementary pathways through which data-driven governance improves emergency collaboration.

To address these gaps, we use China’s National Big Data Comprehensive Pilot Zones as a quasi-natural experiment and construct a provincial panel dataset from 2010 to 2022, utilizing a multi-period difference-in-differences model to estimate whether pilot-zone policies strengthen the policy-text-based institutionalization of emergency collaboration in provincial governance systems. We further examine two complementary mechanisms: emergency-related technological innovation—which captures task-specific technological outputs associated with disaster prevention, risk monitoring, early warning, emergency communication, public safety, rescue, command, and resource allocation—and digital government, which reflects the institutional capacity for data sharing, platform-based coordination, and administrative interoperability. The analysis also examines whether the policy effect varies across regions with different implementation capacities, absorptive

capacities, and emergency-service demands. By focusing on the formal institutionalization of emergency collaboration rather than field-level rescue performance, this study contributes to systems governance and smart-city research by clarifying how data-driven policy experimentation may shape the institutional foundations of emergency collaboration within China's provincial governance context.

2. Theoretical Framework and Hypotheses

2.1. Pilot-Zone Policy and Institutionalized Emergency Collaboration

Emergency collaboration depends on the ability of multiple organizations to share information, coordinate responsibilities, and allocate resources under time pressure and uncertainty. Existing studies show that open and frequent information sharing is essential for improving interorganizational emergency collaboration [20]. However, traditional emergency-management systems often face information silos, fragmented responsibilities, and resource barriers, and departmental segmentation may cause public agencies and social organizations to rely on partial information, thereby weakening joint decision-making and coordinated action [21]. In complex disaster scenarios, hierarchical command structures may also be constrained by long decision chains and rigid feedback mechanisms, making it difficult to adapt to rapidly changing emergency conditions [22,23].

From a systems perspective, data-driven governance can help address these coordination constraints by reshaping the informational and institutional foundations of emergency collaboration. Data resources and digital technologies can improve emergency collaboration in two main ways: first, they support cross-departmental information integration and shared situational awareness, which are essential for collaborative emergency-management networks [24]; second, digital platforms and intelligent decision-support tools can strengthen risk monitoring, early warning, scenario analysis, and resource allocation, thereby improving the analytical basis of collaborative emergency decision-making [25]. Thus, data empowerment does not simply add technical tools to emergency management; it changes the relational infrastructure through which organizations exchange information, define responsibilities, and coordinate action.

China's National Big Data Comprehensive Pilot Zones provide an institutional setting in which these data-driven governance mechanisms can be examined. The pilot-zone policy is a bundled systemic intervention rather than a single infrastructure program. Its main components can be grouped into four dimensions: data and infrastructure integration, data sharing and circulation, innovation and application development, and institutional and governance experimentation. The first and third dimensions expand the technological and analytical capacities available for emergency governance, whereas the second and fourth strengthen platform integration, administrative interoperability, and cross-departmental coordination routines. By jointly reshaping informational, technological, and institutional conditions, the policy is expected to strengthen the formal institutionalization of emergency collaboration [26]. Because the DID variable captures the overall policy package, its coefficient represents the average effect of the bundled intervention. Accordingly, this study proposes the following hypothesis:

H1. *The establishment of National Big Data Comprehensive Pilot Zones positively affects institutionalized emergency collaboration.*

2.2. Emergency-Related Technological Innovation as a Mediating Pathway

The National Big Data Comprehensive Pilot Zone policy can promote emergency-related technological innovation by reshaping the regional data and innovation environment. As policy laboratories for data resource management, sharing, application, and circu-

lation; data-center integration; and big data industrial development, pilot zones provide institutional and infrastructural support for the standardized processing and cross-domain use of heterogeneous data [27]. By improving data circulation and reducing information asymmetry, pilot-zone construction can facilitate knowledge exchange, factor allocation, and innovation collaboration among governments, firms, and research organizations [28]. From the perspective of innovation diffusion, digital innovation spreads through communication channels, organizational adoption, and social-system adaptation; pilot zones can accelerate this process by providing digital platforms, policy incentives, and demonstration effects [29].

However, not all technological innovation is equally relevant to emergency governance: general regional patent output may capture broad innovation capacity, but it does not necessarily reflect technologies that directly support disaster prevention, emergency response, public safety, or cross-departmental coordination. Therefore, this study focuses on emergency-related technological innovation, which refers to technological outputs associated with risk monitoring, early warning, emergency communication, disaster assessment, firefighting, flood control, rescue, emergency command, and resource allocation, as these technologies are more directly connected to the operational and informational tasks of emergency governance.

Emergency-related technological innovation provides a technical-capacity pathway through which data-driven policy experimentation can support the institutionalization of emergency collaboration. In emergency governance, collaboration depends not only on administrative coordination but also on the capacity to integrate heterogeneous information, identify risks, assess evolving disaster conditions, and allocate resources under uncertainty. Technologies related to data fusion, intelligent warning, spatiotemporal analysis, emergency communication, command platforms, and resource dispatch can help public agencies build shared situational awareness and develop more standardized coordination procedures [30–32]. In this sense, technological innovation does not automatically improve emergency collaboration; it contributes to institutionalized collaboration when it is closely connected to emergency-management tasks and embedded in administrative routines.

Therefore, emergency-related technological innovation is not only an outcome of pilot-zone construction but also a mediating pathway through which data-driven policy experimentation is translated into institutionalized emergency collaboration, and is stimulated by pilot zones by improving data circulation, digital infrastructure, platform development, and regional innovation ecosystems. In turn, these task-relevant technological innovations enhance the informational and analytical capacities needed for cross-departmental coordination, joint response, and resource integration. Accordingly, this study proposes the following hypothesis:

H2. *Emergency-related technological innovation mediates the relationship between National Big Data Comprehensive Pilot Zones and institutionalized emergency collaboration.*

2.3. Digital Government as a Mediating Pathway

Digital government provides an institutional pathway through which data-driven policy experimentation can enhance emergency collaboration, as it is not only the application of digital tools in public administration, but also a governance transformation that integrates digital strategies, data resources, administrative processes, and public service delivery [33,34]. From the perspective of holistic governance, digital government helps public organizations move beyond fragmented departmental structures by promoting coordination, integration, and cross-boundary service provision [35,36]; therefore, its development can strengthen the institutional conditions under which data resources are transformed into collaborative governance capacity.

The National Big Data Comprehensive Pilot Zone policy can promote such development by improving data infrastructure, encouraging data sharing, and supporting platform-based administrative integration. Pilot-zone construction provides local governments with stronger incentives and institutional conditions to integrate scattered departmental data into unified digital platforms, which can reduce information barriers, improve interdepartmental interoperability, and support more standardized coordination procedures. In this sense, pilot-zone policy does not only stimulate technological upgrading; it also promotes institutional reconstruction by embedding data circulation and platform integration into government operations.

Digital government further enhances institutionalized emergency collaboration in several ways: integrated digital platforms can connect emergency-related data from multiple departments, allowing public agencies to share information and build a common operational picture; interoperability arrangements, such as standardized data interfaces and coordinated administrative procedures, can reduce the organizational friction that often delays emergency response [37]; in large-scale public emergencies, it can support real-time information sharing, joint decision-making, and coordinated action among government agencies and other actors [38]. Thus, digital government functions as an institutional capacity pathway that translates data-driven policy experimentation into more systematic emergency collaboration. Accordingly, this study proposes the following hypothesis:

H3. *Digital government mediates the relationship between National Big Data Comprehensive Pilot Zones and institutionalized emergency collaboration.*

This study constructs a dual-mediation framework to reveal how the National Big Data Comprehensive Pilot Zone policy affects institutionalized emergency collaboration. The logical relationship among the research hypotheses is shown in Figure 1.

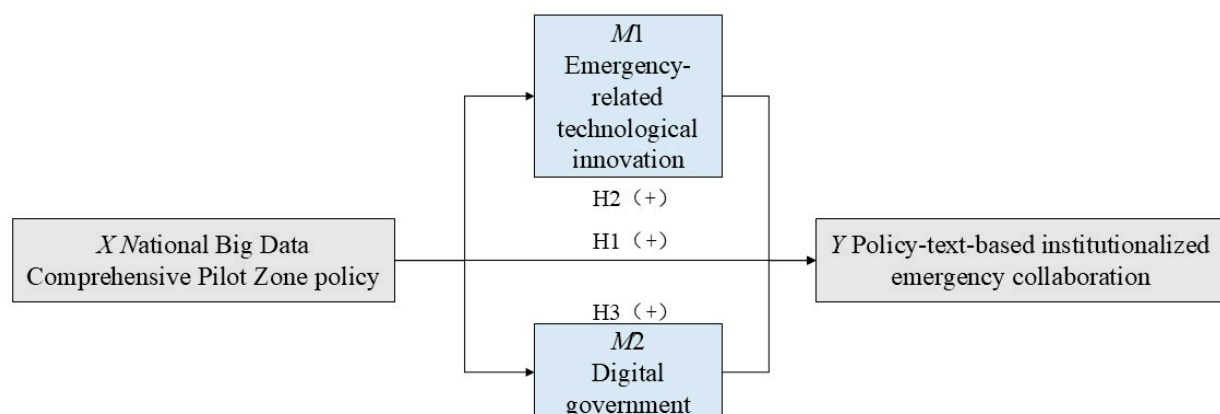


Figure 1. Theoretical framework and hypothesized mechanisms.

The two pathways are analytically distinct but functionally interdependent. Integrated digital-government capacity provides data access, interoperable platforms, standardized procedures, institutional demand, and application scenarios through which emergency-related technologies can be adopted and routinized. In turn, technologies for real-time sensing, prediction, communication, and resource dispatch expand the functional capacity of digital-government platforms and make cross-departmental coordination operational. The two pathways may therefore form a mutually enabling technology–institution coupling process.

3. Materials and Methods

3.1. Research Design and Data

This study uses China's National Big Data Comprehensive Pilot Zone policy as a quasi-natural experiment to examine whether data-driven policy experimentation strengthens the policy-text-based institutionalization of emergency collaboration. The empirical analysis is based on a multi-period difference-in-differences (DID) design, which compares changes in policy-text-based institutionalized emergency collaboration between pilot and non-pilot provinces before and after policy implementation. DID is a widely used approach for identifying policy effects when treatment is introduced to some units but not others over time [39].

The sample covers 30 provinces, autonomous regions, and municipalities in China from 2010 to 2022. To ensure comparability in policy timing, the implementation year of the pilot-zone policy is set as 2016 for all treated regions. Although Guizhou initiated pilot-zone construction earlier, it was officially approved as the first national pilot zone in 2016, and the majority of national pilot zones were also approved that year; therefore, using this as the unified treatment year avoids inconsistent treatment timing across pilot regions.

The dataset combines five types of information: provincial emergency-management policy texts, pilot-zone policy information, emergency-related patent statistics, digital government evaluation data, and socioeconomic control variables. The dependent variable is constructed from provincial emergency-management-related documents retrieved from the Peking University Law Database (PKULAW), and it captures the formal codification of collaborative mechanisms, information-sharing arrangements, joint-response procedures, and multi-actor coordination rules in provincial policy documents. The pilot-zone treatment variable is coded according to official policy documents issued by the State Council and the National Development and Reform Commission. Patent records are obtained from IncoPat Global Patent Database and screened at the province-year level by IPC/CPC classifications and title–abstract keywords to identify emergency-related granted patents. Socioeconomic indicators are mainly obtained from the China Statistical Yearbook and provincial statistical yearbooks. Digital government data are taken from the Survey and Evaluation Report on the Integrated Government Service Capacity of Provincial Governments and Key Cities.

3.2. Variables and Measurement

The dependent variable is institutionalized emergency collaboration (EC). Following studies that use policy texts and keyword-based measurements to identify policy attention and institutional orientation [40,41], we construct a provincial policy-text corpus from the Peking University Law Database (PKULAW), which includes provincial laws, regulations, rules, and normative documents related to emergency management issued from 2010 to 2022. Keywords associated with emergency collaboration, such as “collaboration”, “cross-departmental coordination”, “joint response”, “information sharing platform”, and “multi-subject cooperation”, are counted by province-year, and the annual keyword frequency is used to capture the extent to which collaborative emergency governance is institutionalized in provincial policy documents. This variable is logarithmically transformed. Chinese keywords were used in the original coding, and their English translations are reported here for readability. It should be noted that this measure captures the institutional codification of emergency collaboration in provincial policy documents rather than field-level operational performance. Policy texts provide observable evidence of whether collaborative mechanisms, information-sharing arrangements, joint-response procedures, and multi-actor coordination rules are formally incorporated into provincial emergency-governance systems; therefore, the dependent variable should be interpreted as policy-text-based institutionalized emergency collaboration, not as a direct measure of

response time, rescue efficiency, or on-site inter-agency performance. This measurement strategy is appropriate for examining the institutionalization of emergency collaboration.

The core independent variable is the National Big Data Comprehensive Pilot Zone (BigData), constructed as a DID treatment variable: if province *i* belongs to a pilot region and year *t* is 2016 or later, BigData equals 1; otherwise, it equals 0. The treated regions include Guizhou, Beijing, Tianjin, Hebei, Inner Mongolia, Liaoning, Henan, Shanghai, Chongqing, and Guangdong.

This study further examines two mediating variables. The first is emergency-related technological innovation (EmergencyInno). EmergencyInno is constructed from the IncoPat Global Patent Database. Specifically, this study identifies emergency-related patents through a two-step screening procedure that combines IPC/CPC classification and keyword matching [42,43]. First, patent records are preliminarily screened according to core IPC/CPC classes closely related to emergency-governance technologies, including G08B for alarm, warning, and signal systems; A62B for rescue, protection, and escape equipment; A62C for firefighting and fire-extinguishing equipment; G01W for meteorological monitoring; G01V for geophysical detection, including earthquake and geological detection; and E02B for water conservancy, flood control, and drainage-related engineering. These classes correspond to key technological domains in disaster prevention, emergency response, public safety, risk monitoring, early warning, rescue, firefighting, flood control, and emergency infrastructure support. Second, the preliminarily identified patent records are further screened using emergency-governance-related keywords in patent titles and abstracts. The keyword dictionary includes terms such as “emergency”, “disaster”, “risk monitoring”, “early warning”, “rescue”, “firefighting”, “flood control”, “earthquake”, “public safety”, “emergency command”, “emergency communication”, “resource dispatch”, and “emergency platform”. Chinese keywords are used in the actual patent retrieval and screening process, and their English translations are reported here for readability. A patent is included in the emergency-related patent subset when it falls within the selected IPC/CPC classes and is substantively related to emergency-governance tasks according to title–abstract keyword screening; this dual screening rule helps reduce the risk of including patents that belong to broad technical categories but are weakly related to emergency governance. The province–year value of EmergencyInno is calculated according to the number of emergency-related granted patents in each province and year, assigned based on the applicant’s provincial location and the grant year, respectively. The variable is measured as the logarithm of one plus the number of emergency-related granted patents.

The second mediator is integrated digital-government service capacity (Digital), measured using the province-level overall index reported in the Survey and Evaluation Report on the Integrated Government Service Capacity of Provincial Governments and Key Cities. The assessment was commissioned by the E-Government Office of the General Office of the State Council and conducted by the E-Government Research Center of the Central Party School (National Academy of Governance). Developed with reference to the United Nations E-Government Development Index framework, it combines standardized data collected from national and provincial integrated government-service platforms with user-experience-based evaluation. The provincial evaluation framework comprises five first-level dimensions: service effectiveness, processing maturity, channel completeness, service-item coverage, and service-guide accuracy. These dimensions were further operationalized through 21 second-level and 55 third-level indicators. The published overall score is expressed on a 0–100 scale and is transformed as $\ln(1 + \text{score})$ in the empirical analysis. Because the five core dimensions remain broadly stable while some lower-level

indicators are adjusted to reflect annual policy priorities, we consistently use the aggregate index across years and acknowledge the adjustments as a measurement limitation. Following existing studies on e- and digital government capability [44,45], the overall provincial score is used as a proxy for digital government development.

The control variables include economic development level (GDP), urbanization level (Urban), road infrastructure (Road), technology marketization level (TechMarket), public safety expenditure (SafetyExp), and information technology workforce (ITWorker). GDP, Road, TechMarket, SafetyExp, and ITWorker are logarithmically transformed, while Urban is measured by the share of urban population in the total population. Missing values are filled using mean imputation when the missing proportion is small and no alternative official source is available. Table 1 reports the descriptive statistics of the main variables.

Table 1. Descriptive statistics of variables.

Variables	N	Mean	SD	Min	Median	Max
EC	390	4.979	1.226	1.792	5.014	7.752
BigData	390	0.180	0.384	0	0	1
EMInno	390	6.230	1.568	1.609	6.424	9.303
Digital	390	3.451	1.309	0	4.348	4.595
GDP	390	9.814	0.910	7.043	9.902	11.772
Urban	390	0.595	0.124	0.338	0.582	0.896
Road	390	9.861	0.813	7.213	9.868	11.608
TechMarket	390	4.873	1.874	−0.562	4.869	8.981
SafetyExp	390	5.472	0.683	3.450	5.516	7.264
ITWorker	390	1.962	1.034	−0.511	1.864	4.617

To provide a descriptive background before model estimation, Figure 2 plots the kernel density distributions of institutionalized emergency collaboration before and after the implementation of the pilot-zone policy. For visual comparability, the figure uses the core comparison window of 2011–2015 and 2016–2020. The post-policy distribution shifts to the right relative to the pre-policy distribution, suggesting an overall increase in institutionalized emergency collaboration after the implementation of the National Big Data Comprehensive Pilot Zone policy.

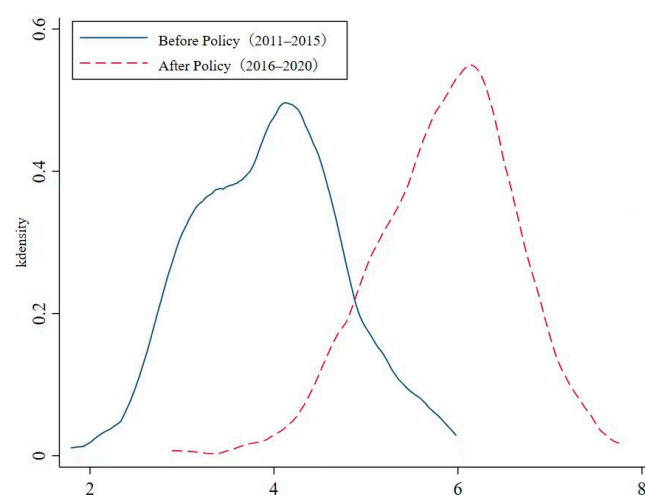


Figure 2. Distribution of institutionalized emergency collaboration before and after policy implementation.

3.3. Empirical Specification

The baseline DID model is specified as follows:

$$EC_{it} = \beta_0 + \beta_1 DID_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

where EC_{it} denotes institutionalized emergency collaboration in province i in year t ; $BigData_{it}$ is the DID treatment variable; X_{it} represents the vector of control variables; μ_i denotes province fixed effects, which control for time-invariant provincial characteristics; λ_t denotes year fixed effects, which absorb common shocks across years; ε_{it} is the error term; and the coefficient of interest is β_1 . A significantly positive β_1 indicates that the pilot-zone policy improves institutionalized emergency collaboration.

To examine the mediating mechanisms, this study estimates two sets of mediation models:

$$EMInno_{it} = \alpha_0 + \alpha_1 DID_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

$$EC_{it} = \delta_0 + \delta_1 DID_{it} + \delta_2 EMInno_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

$$Digital_{it} = \theta_0 + \theta_1 DID_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

$$EC_{it} = \psi_0 + \psi_1 DID_{it} + \psi_2 Digital_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (5)$$

If both α_1 and δ_2 are significant in Equations (2) and (3) above, the results are consistent with an emergency-related technological innovation pathway; if both coefficients in Equations (4) and (5) are significant, the results are consistent with a digital government pathway.

3.4. Robustness and Heterogeneity Tests

In this study, we conduct four robustness checks: first, the sample period is shortened to 2010–2019 to reduce the potential influence of the COVID-19 pandemic; second, municipalities directly under the central government are excluded because they differ from ordinary provinces in administrative status, fiscal capacity, and policy resources; third, the dependent variable is Winsorized to reduce the influence of extreme values; fourth, a propensity score matching difference-in-differences approach is used to reduce potential selection bias caused by observable covariate imbalance between pilot and non-pilot provinces. Additional checks introduce province-specific linear time trends and one-year lagged mediators to assess sensitivity to gradual unobserved trends and the temporal ordering of the proposed mechanisms.

Heterogeneity analyses are conducted from three perspectives: regional heterogeneity, dividing provinces into eastern, central, and western regions; income heterogeneity, grouping provinces according to regional income levels; and population heterogeneity, grouping provinces according to the degree of population aging. These tests help assess whether the effect of data-driven policy experimentation varies across different socioeconomic and demographic contexts.

4. Results

4.1. Baseline Regression Results

Table 2 reports the baseline regression results for the effect of the National Big Data Comprehensive Pilot Zone policy on institutionalized emergency collaboration. Columns (1)–(3) gradually add province fixed effects, year fixed effects, and control variables. Across all specifications, the coefficient of *BigData* remains positive and statistically significant, indicating that the establishment of pilot zones significantly strengthens the policy-text-based institutionalization of emergency collaboration.

The coefficient of *BigData* is 1.521 and significant at the 1% level in column (1), where only the policy variable is included; decreases to 0.719 but remains statistically significant at the 1% level after province and year fixed effects are added in column (2); and remains positive and significant at the 1% level in column (3), after further controlling for economic

development, urbanization, road infrastructure, technology marketization, public safety expenditure, and information technology workforce. The estimated coefficient is 0.572, suggesting that pilot-zone construction has a robust positive effect on institutionalized emergency collaboration; thus, these results support Hypothesis 1.

Table 2. Estimated effect of the pilot-zone policy on institutionalized emergency collaboration.

Variables	(1)	(2)	(3)
	EC	EC	EC
BigData	1.521 *** (0.142)	0.719 *** (0.088)	0.572 *** (0.082)
Cons	4.706 *** (0.060)	4.850 *** (0.029)	12.747 *** (2.516)
Controls	No	No	Yes
Province FE	No	Yes	Yes
Year FE	No	Yes	Yes
Adj.R ²	0.225	0.885	0.897
N	390	390	390

Notes: Robust standard errors clustered at the province level are reported in parentheses. *** $p < 0.01$.

4.2. Parallel Trend Test

The validity of the DID estimation depends on the parallel trends assumption. To assess the pre-policy dynamics and examine the temporal pattern of the policy effect, we estimate an event-study model, with 2015—the year immediately preceding policy implementation—used as the reference period, as shown in Figure 3.

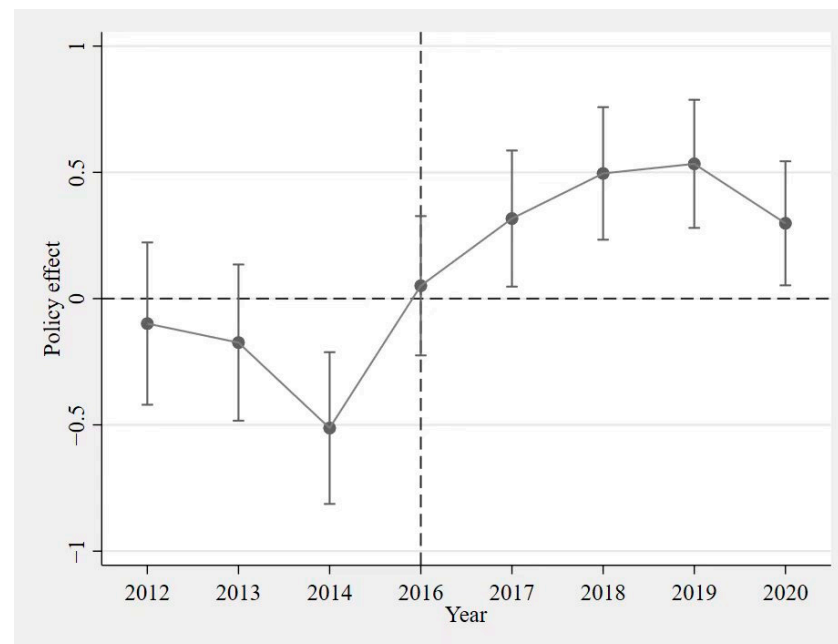


Figure 3. Dynamic treatment effects before and after pilot-zone implementation. The horizontal dashed line indicates a zero policy effect, while the vertical dashed line marks the policy implementation year, 2016.

Following policy implementation, the coefficient for 2016 is small and statistically insignificant, suggesting that the effect of the pilot-zone policy did not emerge immediately. The estimated coefficients become positive and statistically significant from 2017 onward, increase through 2019, and remain positive in 2020, although the magnitude

declines slightly. This pattern is consistent with a delayed and gradually accumulating policy effect, while the decline in 2020 may partly reflect the disruptive influence of the COVID-19 pandemic.

4.3. Mediation Effect Test

To examine the transmission mechanisms of the pilot-zone policy, this study tests whether emergency-related technological innovation and digital government are associated with the link between pilot-zone construction and institutionalized emergency collaboration. The results are reported in Table 3.

Table 3. Mediation effect results.

Variables	(1) EMInno	(2) EC	(3) Digital	(4) EC
BigData	0.103 ** (0.051)	0.949 *** (0.105)	0.312 ** (0.150)	0.899 *** (0.098)
EMInno		0.588 *** (0.091)		
Digital				0.356 *** (0.042)
Controls	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Adj.R ²	0.967	0.834	0.765	0.850
N	390	390	390	390

Notes: Robust standard errors clustered at the province level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$.

Columns (1) and (2) in Table 3 report the results for the emergency-related technological innovation pathway. The former shows that the National Big Data Comprehensive Pilot Zone policy has a significantly positive effect on emergency-related technological innovation, with a coefficient of 0.103 at the 5% level, indicating that pilot-zone construction increases task-relevant technological innovation related to emergency governance. The latter further shows that emergency-related technological innovation is positively associated with institutionalized emergency collaboration, with a coefficient of 0.588 at the 1% level. The coefficient of BigData remains positive and statistically significant, suggesting that emergency-related technological innovation does not fully absorb the association between pilot-zone construction and institutionalized emergency collaboration. These results are consistent with the proposed emergency-related technological innovation pathway; specifically, pilot-zone construction may strengthen the institutionalization of emergency collaboration by promoting technologies related to risk monitoring, early warning, emergency communication, disaster assessment, command support, and resource allocation. Therefore, Hypothesis 2 is supported.

Columns (3) and (4) report the results for the digital government pathway: the former shows that the pilot-zone policy significantly promotes digital government development, with a coefficient of 0.312 at the 5% level; the latter further shows that digital government is positively associated with institutionalized emergency collaboration, with a coefficient of 0.356 at the 1% level. The coefficient of BigData also remains positive and statistically significant after Digital is included in the model. These findings suggest that digital government constitutes an institutional pathway through which pilot-zone construction may support the institutionalization of emergency collaboration; by promoting data sharing, platform-based coordination, administrative interoperability, and standardized interdepartmental procedures, digital government can help transform data-driven policy experimentation into more

formalized collaborative emergency-governance arrangements. Therefore, Hypothesis 3 is supported.

4.4. Robustness Test

To enhance the credibility of the estimation results, we conduct a series of robustness checks from two perspectives: first, we examine whether the baseline policy effect is sensitive to sample restrictions, outlier treatment, and matching procedures; second, we conduct additional checks to address potential concerns about DID identification and mechanism interpretation. The results are reported in Table 4.

Table 4. Robustness test results.

Variables	(1) Sample Shortened	(2) Municipalities Excluded	(3) Outlier Winsorization	(4) PSM-DID	(5) Linear Trend	(6) L.EMInno	(7) L.Digital
BigData	0.531 *** (0.103)	0.378 *** (0.078)	0.478 *** (0.082)	0.674 *** (0.108)	0.387 ** (0.174)	0.933 *** (0.120)	0.718 *** (0.120)
L.EMInno						0.497 *** (0.106)	
L.Digital							0.351 *** (0.053)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj.R ²	0.859	0.894	0.896	0.891	0.913	0.822	0.838
N	300	338	390	241	390	360	360

Notes: Robust standard errors clustered at the province level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$. Columns (6) and (7) use one-year lagged mediators.

Columns (1)–(4) report the baseline robustness checks. Column (1) shortens the sample period to 2010–2019 to reduce the potential interference of the COVID-19 pandemic; column (2) excludes municipalities directly under the central government, namely Beijing, Shanghai, Tianjin, and Chongqing, because these regions differ from ordinary provinces in administrative status, fiscal resources, and policy capacity; and column (3) Winsorizes the dependent variable at the 5% and 95% levels to reduce the influence of extreme values. In these three columns, the coefficient of BigData remains positive, with estimated values of 0.531, 0.378, and 0.478, respectively; is significant at the 1% level in columns (1) and (3); and is significant at the 1% level in column (2). Column (4) reports the PSM-DID result based on the matched sample; the coefficient remains positive and statistically significant, indicating that the baseline conclusion is not driven by observable covariate imbalance between pilot and non-pilot provinces.

Columns (5)–(7) provide additional identification and mechanism robustness checks. Column (5) adds province-specific linear time trends to control for unobserved provincial trends that may evolve gradually over time. The coefficient of BigData remains positive and significant at the 5% level, with an estimated value of 0.387, suggesting that the baseline effect is not simply driven by province-specific long-term trends. Columns (6) and (7) replace the contemporaneous mediators with one-year lagged mediators: in the former, lagged emergency-related technological innovation is positively associated with institutionalized emergency collaboration, with a coefficient of 0.497 at the 1% level; in the latter, lagged digital government is also positively associated with institutionalized emergency collaboration, with a coefficient of 0.351 at the 1% level. These results provide additional evidence consistent with the proposed technological and institutional pathways.

Overall, the robustness checks show that the positive effect of the National Big Data Comprehensive Pilot Zone policy on institutionalized emergency collaboration remains stable after excluding the COVID-19 period, excluding municipalities, Winsorizing the dependent variable, applying PSM-DID, and controlling for province-specific linear trends. The lagged-mediator results further suggest that emergency-related technological innovation and digital government are positively associated with the subsequent institutionalization of emergency collaboration.

Figure 4 reports the diagnostic results of the PSM procedure: Panel (a) presents the standardized percentage bias of covariates before and after matching, and Panel (b) shows the common-support distribution of propensity scores for treated and untreated observations. The results indicate that matching substantially reduces covariate imbalance and that most treated observations fall within the common-support region; therefore, the matched sample provides a more comparable basis for testing the policy effect of the National Big Data Comprehensive Pilot Zones.

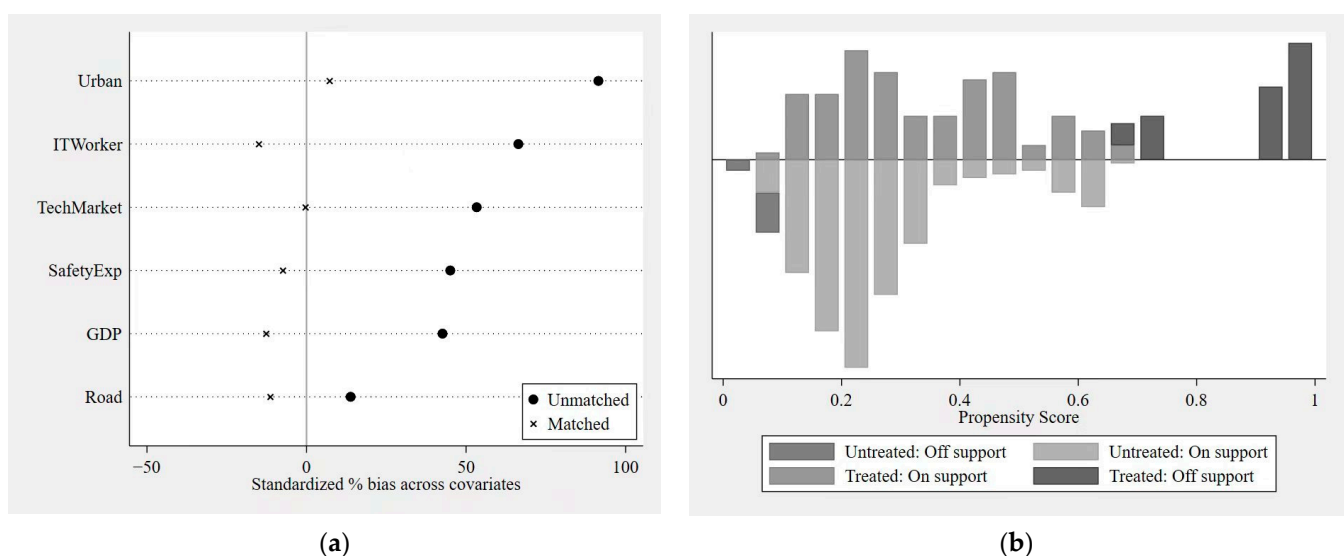


Figure 4. PSM diagnostic results. (a) Covariate balance before and after matching; The vertical reference line at zero indicates perfect covariate balance, corresponding to zero standardized bias. (b) common support of propensity scores.

4.5. Heterogeneity Analysis

The baseline regression and robustness checks show that the National Big Data Comprehensive Pilot Zone policy has a significant positive effect on institutionalized emergency collaboration. However, from a systems governance perspective, data-driven policy experimentation does not generate uniform effects across all regional contexts: the transformation of data infrastructure into institutionalized emergency collaboration depends on whether local governments possess sufficient implementation capacity, absorptive capacity, and governance demand to convert policy experimentation into routinized coordination arrangements.

This study therefore conducts heterogeneity analyses from three theoretically relevant dimensions—geographic region, income level, and population aging—which are not merely descriptive classifications, but reflect different contextual mechanisms that may condition the policy effect. First, geographic region captures differences in digital infrastructure, administrative capacity, and socio-technical readiness; regions with stronger digital foundations and more mature governance capacity are more likely to transform data resources into interdepartmental coordination mechanisms. Second, income level reflects fiscal capacity, technology absorption capacity, and the marginal space for institutional im-

provement. Data-driven policy experimentation may be less effective in low-income regions with insufficient implementation resources, while high-income regions may already have relatively mature digital governance systems, leaving less room for additional improvement. Third, population aging captures emergency-service demand and social vulnerability. Aging regions face stronger needs for emergency medical support, community-level risk monitoring, targeted resource allocation, and cross-departmental service coordination; therefore, demographic pressure may strengthen the demand-side conditions under which data-driven emergency collaboration becomes institutionally salient.

Accordingly, the heterogeneity analysis is designed to examine whether the effect of pilot-zone construction varies across regions with different levels of implementation capacity, absorptive capacity, and emergency-service demand. Regional, income, and aging heterogeneity are examined by dividing provinces into eastern, central, and western regions according to the regional classification of the National Bureau of Statistics; grouping provinces according to regional income levels; and grouping provinces according to the degree of population aging, respectively. The results are reported in Table 5.

Table 5. Heterogeneity test results.

Variables	(1) Eastern	(2) Central Region	(3) Western	(4) High	(5) Medium Income	(6) Low	(7) Severely	(8) Moderately Aging	(9) Mildly
BigData	0.409 *** (0.148)	0.352 (0.264)	0.273 (0.172)	0.441 * (0.260)	0.500 *** (0.187)	0.249 (0.174)	0.632 *** (0.131)	0.248 * (0.143)	0.604 (0.434)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj.R ²	0.934	0.884	0.866	0.928	0.903	0.873	0.917	0.898	0.876
N	143	104	143	91	143	156	182	156	52

Notes: Robust standard errors clustered at the province level are reported in parentheses. *** $p < 0.01$, * $p < 0.10$.

To provide a more intuitive presentation of the heterogeneity results, Figure 5 visualizes the estimated DID coefficients and confidence intervals across the three grouping dimensions reported in Table 6. Panels (a), (b), and (c) correspond to regional, income-level, and aging-degree heterogeneity, respectively.

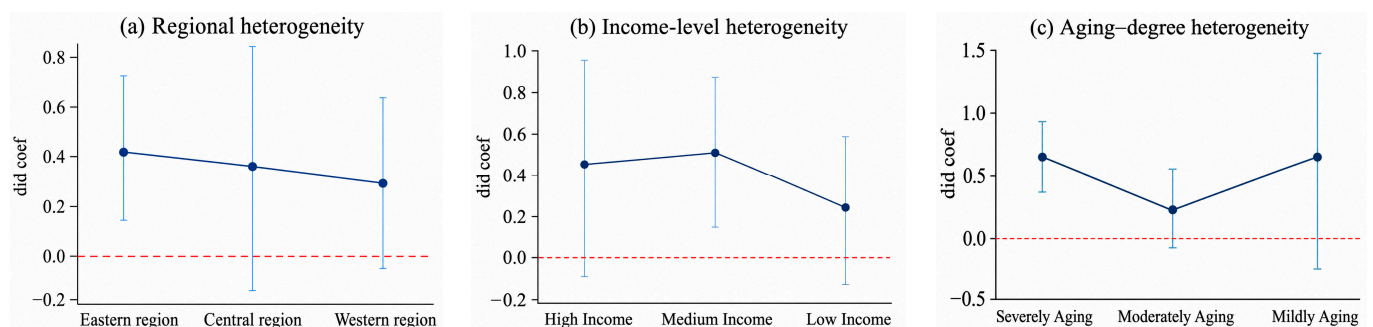


Figure 5. Heterogeneity across regional, income-level, and aging-degree groups.

Columns (1)–(3) of Table 6 show regional heterogeneity in the effect of the National Big Data Comprehensive Pilot Zone policy: the coefficient of BigData is positive and significant in eastern regions, with an estimated value of 0.409 at the 1% level, while those for central and western regions are not statistically significant. This result is consistent with the implementation-capacity argument: the policy effect of big data pilot zones depends not only on formal policy adoption but also on whether local governments can integrate digital infrastructure, data platforms, administrative procedures, and cross-departmental

coordination rules. Eastern regions generally have stronger digital infrastructure, denser innovation resources, and more mature administrative coordination capacity, which makes them better able to convert pilot-zone construction into institutionalized emergency collaboration. In contrast, central and western regions may face greater constraints in digital infrastructure, fiscal input, and administrative interoperability, weakening the conversion of data-driven policy experimentation into formal collaborative arrangements.

Table 6. IPC/CPC classifications for emergency-related patent screening.

IPC/CPC	Technical Meaning	Inclusion Rule
G08B	Alarm, warning, and signal systems	Included
A62B	Rescue, protection, and escape equipment	Included
A62C	Firefighting and fire-extinguishing equipment	Included
G01W	Meteorological monitoring	Included
G01V	Geophysical, earthquake, and geological detection	Included
E02B	Water conservancy, flood control, and drainage engineering	Included

Columns (4)–(6) report heterogeneity by income level. The policy effect is strongest in middle-income regions, where the coefficient of BigData is 0.500 and significant at the 1% level; the coefficient is also positive in high-income regions but only significant at the 10% level, while the effect in low-income regions is not statistically significant. This pattern can be interpreted through the lens of absorptive capacity and marginal improvement space. Low-income regions may lack sufficient fiscal resources, technical personnel, and platform-building capacity to fully absorb the institutional opportunities created by the pilot-zone policy; high-income regions, by contrast, may already have relatively advanced digital government systems and emergency-management arrangements before the policy intervention, which reduces the marginal effect of pilot-zone construction. Middle-income regions may combine sufficient absorption capacity with greater room for institutional improvement, making the policy effect more pronounced.

Columns (7)–(9) present the results by population aging. The coefficient of BigData is 0.632 and significant at the 1% level in severely aging regions, while it is positive and weakly significant in moderately aging regions and not statistically significant in mildly aging regions. This result supports the demand-pressure argument: population aging increases the need for emergency medical support, community care, risk monitoring, targeted resource allocation, and cross-departmental service coordination; in severely aging regions, local governments face stronger incentives to institutionalize data-driven collaboration because fragmented emergency systems are less capable of responding to complex and vulnerable populations. Therefore, the pilot-zone policy is more likely to be translated into formal collaborative arrangements where emergency-service demand is stronger.

Overall, the heterogeneity results suggest that the governance effect of data-driven policy experimentation is conditional rather than automatic. The National Big Data Comprehensive Pilot Zone policy is more likely to promote institutionalized emergency collaboration when local governments possess sufficient implementation capacity, regions have adequate absorptive capacity and room for improvement, and demographic pressure creates stronger demand for coordinated emergency services. These findings enrich the baseline results by showing that data-driven emergency collaboration depends on the alignment between policy intervention, local capacity, and governance demand.

5. Discussion

5.1. Data-Driven Policy Experimentation as a Systemic Governance Mechanism

The results show that the National Big Data Comprehensive Pilot Zone policy significantly improves institutionalized emergency collaboration, indicating that data-driven policy experimentation can generate governance effects beyond economic, technological, industrial, or environmental outcomes. In the field of emergency management, collaboration is often constrained by fragmented information, departmental boundaries, and insufficient coordination routines. The pilot-zone policy helps address these constraints by promoting data infrastructure construction, data sharing, and digital governance arrangements; therefore, its effect on institutionalized emergency collaboration can be understood as the result of improving the informational and organizational conditions for cross-boundary emergency governance. Figure 6 provides a conceptual interpretation of why this policy effect occurs.

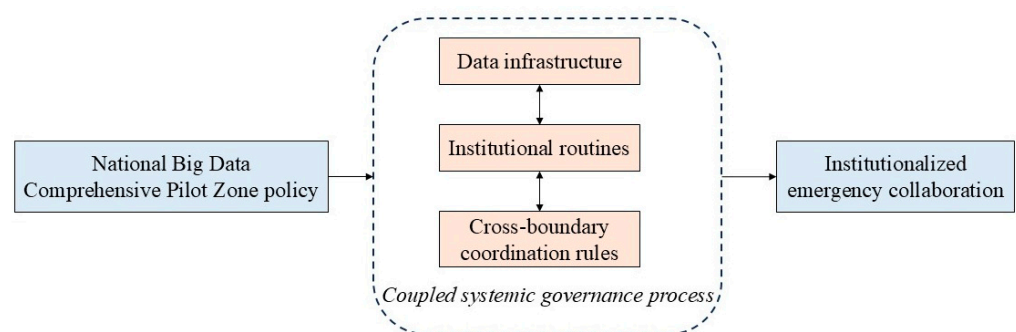


Figure 6. Policy pathways to institutionalized emergency collaboration.

Figure 6 further clarifies the internal logic of this systemic mechanism: first, data infrastructure provides the informational foundation for emergency collaboration by enabling the collection, integration, and circulation of risk-related information across departments and regions; second, institutional routines translate data availability into regularized administrative practices, such as standardized information reporting, joint consultation, platform-based decision-making, and coordinated resource allocation; third, cross-boundary coordination rules define how different public agencies share responsibilities, exchange data, and respond jointly under uncertainty. These three components are mutually reinforcing: data infrastructure without institutional routines may remain a technical facility; institutional routines without cross-boundary rules may reproduce departmental fragmentation; and coordination rules without reliable data infrastructure may lack real-time decision support. Therefore, the governance effect of pilot-zone policy emerges from the coupling of data, institutions, and coordination arrangements.

This finding extends existing research on National Big Data Comprehensive Pilot Zones by shifting attention from development-oriented to public safety governance outcomes. Previous studies have mainly examined whether big data pilot zones promote economic growth, technological innovation, industrial transformation, green development, and environmental improvement, whereas we show that such policies can also improve institutionalized emergency collaboration, which is a key governance capacity in smart-city-regional systems. More importantly, the results suggest that the value of data-driven policy experimentation lies not only in building digital infrastructure, but also in enabling public agencies to use data within institutionalized coordination processes. In this sense, the main effect found in this study supports the argument that data-driven policy experimentation can function as a systemic governance mechanism for strengthening emergency collaboration in complex urban and regional governance contexts.

5.2. Technological and Institutional Pathways: Complementarity and Analytical Boundaries

The aggregate digital index comprises five first-level dimensions: service effectiveness, processing maturity, channel completeness, service-item coverage, and service-guide accuracy. Among these dimensions, processing maturity is most directly aligned with the proposed emergency-collaboration mechanism because it assesses one-stop online processing and explicitly incorporates data-sharing capacity, including government-data catalogue compilation and integrated online handling. Channel completeness and service-item coverage provide complementary support by broadening access channels and the range of services integrated into common platforms, whereas service effectiveness and service-guide accuracy primarily capture user-facing outcomes and information quality. This interpretation identifies conceptual proximity rather than a statistically estimated ranking, because the empirical models use the aggregate index. Representative practices documented in the official evaluation report support this mechanism. Zhejiang connected 319 ministerial and subnational business systems, standardized the handling of 3638 service items, and used system integration, data sharing, and parallel-process redesign to deliver 56 multi-department “one-event” services. Jilin similarly developed data-sharing and exchange, data supply–demand matching, electronic-certificate, and full-process approval systems, enabling five administrative levels to operate through a common platform. These practices illustrate how processing maturity and data sharing can translate digital-government capacity into standardized cross-departmental coordination.

At the same time, these two pathways should not be interpreted as completely isolated processes: in practice, emergency-related technological innovation and digital government may be mutually reinforcing. On the one hand, a more developed digital government system can provide institutional demand, data access, platform infrastructure, and application scenarios for emergency-related technological innovation. For example, integrated government platforms and standardized data-sharing procedures may create stronger incentives for technologies related to risk monitoring, emergency communication, intelligent warning, and resource dispatch. On the other hand, emergency-related technological innovation can strengthen the functional capacity of digital government by improving data processing, real-time sensing, predictive analysis, and decision-support capabilities. In this sense, emergency-related technological innovation and digital government may form a technology–institution coupling process in which technical tools and administrative arrangements co-evolve.

Therefore, the findings should be interpreted as evidence of complementary but separately estimated mechanisms. The results indicate that pilot-zone construction is associated with both emergency-related technological innovation and digital government development, and that both are positively related to institutionalized emergency collaboration; they do not imply that the two mechanisms operate independently in real governance processes, nor do they provide a definitive causal decomposition of the total policy effect. Future research can further examine the interaction between technological and institutional pathways by testing interaction effects, sequential mediation models, or dynamic feedback mechanisms. Such analysis would help clarify whether the governance value of data-driven policy experimentation depends not only on the presence of emergency-related technological innovation and digital government, but also on how these two capacities are coupled within emergency-management institutions.

5.3. Contextual Heterogeneity in the Policy Effect of Pilot-Zone Construction

The heterogeneity results also provide theoretical insight into the contextual conditions under which data-driven policy experimentation becomes effective. Geographic region, income level, and population aging represent three different but related dimensions of

policy-context fit: regional differences reflect the supply side of implementation capacity, including digital infrastructure, administrative coordination capacity, and socio-technical readiness; income differences reflect the balance between absorptive capacity and marginal improvement space; and aging differences reflect the demand side of emergency governance, especially the pressure for emergency medical support, community-level risk monitoring, and targeted resource coordination. Therefore, the three heterogeneity dimensions jointly indicate that the institutionalization of emergency collaboration requires both supply-side capacity and demand-side pressure. Data-driven policy experimentation is most likely to produce governance effects when local governments are capable of implementing digital reforms and social conditions create strong demand for coordinated emergency services.

First, the stronger effect in eastern regions suggests that data-driven governance policies are more likely to generate institutionalized collaboration where digital infrastructure, fiscal resources, administrative capacity, and policy implementation experience are relatively strong. Pilot-zone construction requires more than the formal adoption of a policy label: it also depends on whether local governments can integrate dispersed data resources, build interoperable platforms, standardize interdepartmental procedures, and translate digital resources into routinized emergency-management arrangements. Regions with stronger administrative and digital foundations are therefore better positioned to absorb the policy experiment and convert it into formal collaborative rules and mechanisms.

Second, the stronger effect in middle-income regions indicates that policy effectiveness also depends on the balance between absorptive capacity and room for institutional improvement. High-income regions may already have relatively mature digital governance systems and emergency-management arrangements, leaving less marginal space for policy-induced improvement; in contrast, low-income regions may face constraints in digital infrastructure, fiscal input, and administrative implementation capacity. Middle-income regions may combine sufficient policy absorption capacity with stronger unmet demand for institutional improvement, making the pilot-zone policy more effective in promoting institutionalized emergency collaboration.

Third, the stronger effect in severely aging regions suggests that demographic pressure can increase the demand for data-driven emergency collaboration. Aging societies tend to face higher needs for emergency medical support, community-level risk monitoring, targeted resource allocation, and cross-departmental service coordination. Under these conditions, data-driven policy experimentation is more likely to be incorporated into emergency-management institutions because local governments face stronger pressure to improve coordination across departments, platforms, and service systems, implying that the governance value of big data pilot zones is more visible when technological and administrative capacity meets concrete emergency-service demand.

These findings also clarify the institutional boundary conditions of this study. The Chinese case provides an important setting for examining how data-driven policy experimentation can strengthen the institutionalization of emergency collaboration, but the results should not be interpreted as universally transferable to all governance systems. China's pilot-zone model operates within a relatively strong state-capacity context, where upper-level policy signals, administrative mobilization, data infrastructure investment, and interdepartmental coordination can be combined through hierarchical policy implementation. In more decentralized, pluralistic, or fragmented institutional settings, the same type of data-driven policy experiment may face different constraints, such as weaker central coordination authority, stricter data-sharing restrictions, stronger local autonomy, or greater institutional fragmentation.

Therefore, the broader implication of this study is not that the Chinese pilot-zone model can be directly replicated elsewhere; instead, the findings suggest a more conditional lesson: data-driven policy experimentation may strengthen institutionalized emergency collaboration when data infrastructure, administrative interoperability, policy implementation capacity, and emergency-service demand are jointly present. For other institutional contexts, the key question is not whether big data policies exist, but whether data resources can be embedded into legitimate, interoperable, and routinized coordination arrangements. Future comparative research could examine whether similar mechanisms operate in decentralized governance systems, federal structures, or countries with different data governance regimes.

6. Conclusions

This study examines whether China's National Big Data Comprehensive Pilot Zones strengthen the policy-text-based institutionalization of emergency collaboration. Using provincial panel data from 2010 to 2022 and a multi-period difference-in-differences design, the analysis shows that pilot-zone construction significantly promotes the formal institutionalization of emergency collaboration in provincial policy systems, suggesting that data-driven policy experimentation can improve the institutional conditions for emergency collaboration by promoting data circulation, platform integration, interdepartmental coordination, and collaborative governance arrangements. However, because the dependent variable is constructed from policy-text indicators, the results should be interpreted as evidence of institutionalized policy attention and formal collaborative arrangements rather than direct evidence of field-level rescue efficiency, response speed, or actual on-site inter-agency performance.

The mechanism analysis indicates that emergency-related technological innovation and digital government serve as two complementary pathways through which pilot-zone construction supports institutionalized emergency collaboration. The former provides task-specific analytical and technical capacity for risk sensing, early warning, emergency communication, disaster assessment, command support, and resource allocation; the latter provides administrative and institutional capacity by supporting data sharing, platform-based coordination, interoperability, and standardized interdepartmental procedures. These results suggest that the governance value of data-driven policy experimentation does not arise from digital technology alone; rather, data resources generate public-governance value when they are embedded in administrative routines, institutional rules, and cross-boundary coordination mechanisms.

The heterogeneity analysis further shows that the policy effect is stronger in eastern, middle-income, and severely aging regions, indicating that the effect of data-driven policy experimentation is conditional rather than automatic. Regions with stronger digital infrastructure and administrative capacity are more likely to convert policy experimentation into institutionalized collaboration; those with sufficient absorptive capacity and greater room for institutional improvement may experience larger marginal gains; and regions facing stronger emergency-service demand, especially those with severe population aging, may have stronger incentives to institutionalize data-driven collaboration in emergency governance.

This study contributes to systems governance, smart-city governance, digital government, and emergency-management research by showing how data-driven policy experimentation can shape the institutional foundations of emergency collaboration. It also extends research on National Big Data Comprehensive Pilot Zones by shifting attention from economic, industrial, and environmental outcomes to public safety governance. At the same time, the findings should be interpreted within clear scope conditions. The analysis is

based on Chinese provincial administrative units and reflects a governance context characterized by strong policy implementation capacity, hierarchical coordination, and state-led digital infrastructure development; therefore, the conclusions should not be generalized mechanically to more decentralized, pluralistic, or low-capacity governance systems.

Future research can extend this study in three directions. First, policy-text indicators can be combined with operational emergency-management data, such as response time, interdepartmental joint actions, resource dispatch records, emergency exercises, and disaster-loss outcomes, to examine whether institutionalized collaboration is translated into field-level performance. Second, future studies can further investigate the interaction, sequencing, and mutual reinforcement between emergency-related technological innovation and digital government, rather than treating them only as analytically distinct mechanisms.

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Data Availability Statement: The policy-text data were retrieved from PKULAW, and statistical data were obtained from publicly available statistical yearbooks and official reports. The processed dataset is available from the corresponding author upon reasonable request. Patent data used to construct emergency-related technological innovation were retrieved from the IncoPat Global Patent Database. Due to database access restrictions, the original patent records cannot be redistributed, but the processed province-year patent counts used in the empirical analysis are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

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