Empowerment and Tension: The Dual Effects and Institutional Adaptation of Embedding Intelligent Technology in Public Health Governance

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Abstract This paper proposes an analytical framework of "dual effects-structural mismatch" to investigate the empowerment mechanisms, tension manifestations, and underlying roots of embedding intelligent technology in public health governance. The study finds that intelligent technology empowers public health governance through data-driven approaches, intelligent analysis, and process reengineering, while simultaneously generating three inherent tensions: privacy erosion, algorithmic bias, and power shift. The root of these tensions lies in the structural mismatch between the logic of the technological system pursuing efficiency and the value logic of public governance adhering to fairness, transparency, and accountability. Based on these findings, this paper constructs a three-dimensional adaptive framework of "technology governance-institutional construction-social collaboration" and proposes an institutional approach that includes embedding explainable algorithms, building resilient regulations, and promoting multi-stakeholder cogovernance, thereby providing theoretical support for smart public health governance.

Key words Intelligent technology, Public health governance, Technological empowerment, Risk tension, Institutional adaptation, Digital government

1 Introduction

In early 2020, the health code, as a digital governance tool during the public health emergency, was rapidly embedded into the national prevention and control system, demonstrating significant advantages in achieving precise management of personnel flow and realtime tracking of epidemic risks[1-2]. However, with its widespread application, controversies over "adding code on code", the deviation of cross-regional data mutual recognition, and incidents of public rights infringement caused by algorithmic misjudgments have frequently emerged[3], revealing that while intelligent technology improves the efficiency of public health governance, it also hides systemic risks. These phenomena point to a central paradox: Why does the embedding of intelligent technology in public health governance simultaneously generate risk alienation while empowering and enhancing efficiency?

Existing research responses to this issue present two opposing tendencies. On the one hand, technological optimism studies focus on the data integration capabilities of intelligent technology, arguing that algorithmic models can effectively reduce the complexity of public health events, and thereby achieve scientific emergency decision-making and precise resource allocation[4-5]. Meng[4] proposed a two-way driving framework of "technology empowerment" and "technology empowerment for rights". Guan *et al.* [5] verified the practical pathway of technology-enabled governance innovation using environmental governance as an example. On the other hand, technological critical studies have revealed the risks following algorithmic embedding. Wang[6] pointed out that algorithmic administration challenges the principles of due process and clear boundaries of rights and responsibilities. Ren[7] systematically analyzed risks such as privacy erosion and responsibility diffusion. Zheng[8] revealed the tension between the pursuit of efficiency and public value using a framework of "validity, temperature, and scale"[8]. The above two pathways reveal the dual aspects of "empowerment" and "discipline", but remain separate, failing to explore the institutional roots of the coexistence of these dual effects. Although Lei[9] has touched upon the interaction between technological logic and institutional adaptation in his explanation of algorithmic administration in the digital government era, research on how technological embedding and institutional response interact in the field of public health remains insufficient.

This paper argues that the flaw in the above binary opposition lies in treating technology and society as separate entities, either falling into technological determinism or regarding institutions as passive responses to technology. In fact, "empowerment" and "tension" are not binary substitutes, but rather mutually nested symbiotic effects within the same institutional process. The root of these risks lies not in the functional flaws of the technology itself, but in the structural mismatch between the expansion of technical rationality and the adherence to public values. When the predictive, standardized, and efficiency-priority features of algorithmic logic are embedded into the field of public health governance, whose core values are fairness, responsiveness, and accountability, the deep inconsistencies in goal prioritization and accountability mechanisms become evident[10-11]. This "structural mismatch" points directly to a systemic maladjustment in the interaction between the technological system and the institutional framework.

Based on this, this paper breaks through the binary opposition of technological determinism and institutional lag, and constructs a three-dimensional adaptive framework of "technology governance-institutional construction-social collaboration". It first explains the inherent logic of intelligent technology empowering pub-

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lic health governance, then reveals the risks accompanying technological embedding and the deep mechanism of "structural mismatch", and finally proposes a collaborative pathway that embeds explainable algorithms into the technological foundation, defines the boundaries of rights and responsibilities through a resilient regulatory system, and reshapes the decision-making ecosystem through multi-stakeholder co-governance. Efficiency is the promise of technology, while resilience is the answer of institutions. Only by constraining technical rationality within the institutional framework of public values can smart public health truly stand firm and go far.

2 Beyond the binary opposition: an analytical framework for embedding intelligent technology in public health governance

Two dominant paradigms exist in research on the embedding of intelligent technology in public health governance: technological determinism and institutional lag theory. The former attributes the improvement of governance efficiency to the autonomous iteration of technology, while the latter attributes governance dilemmas to regulations lagging behind technological change. However, both paradigms presuppose that technology and institutions are separate domains, failing to reveal their mutually constitutive relationship. This chapter examines the theoretical limitations of the above paradigms and subsequently proposes an analytical framework of "dual effects-structural mismatch".

2.1 Examination and limitations of technological determinism and institutional lag theory Technological determinism regards technology as the power of independent evolution, and believes that algorithmic decision-making and big data monitoring naturally improve the effectiveness of public health governance. Qu *et al.*[12] pointed out that since the reform and opening up, China has experienced a paradigm shift "from overall domination to technological governance". Liu[13] reviewed the historical evolution of technocracy from the perspective of the philosophy of technology. However, this paradigm tends to slide toward "technological solutionism", reducing complex public health problems to technology upgrade problems, overestimating the autonomy of technology while underestimating the shaping role of institutions on the direction of technology. Han[14] revealed the four illusions of technological governance: the illusions of rationality, omnipotence, empowerment, and neutrality, pointing out that technology is not a neutral tool, and its effects are deeply constrained by governance contexts and institutional logics. In practice, this paradigm attributes the failure of epidemiological investigations to insufficient algorithm accuracy, while overlooking the fundamental constraints of bureaucratic organizational structure on technological efficacy.

The institutional lag theory implies a linear evolutionary view of "technology first, institutional repair". Huang and Ji[15] pointed out that technological governance faces structural limits in terms of institutional adaptation, organizational embedding, and value integration. Peng[16] revealed the paradox of technological governance: while technology pursues scientization and objectification, it is shaped by political logic in practice, which may exacerbate governance fragmentation. However, this paradigm regards institutions as passive responders, failing to explain why certain institutions can anticipate technological risks, nor why the same technology produces completely different effects in different institutional environments.

The differences between the two paradigms in core dimensions are shown in Table 1.

Table 1 Comparison of technological determinism and institutional lag theory

Comparison dimensions	Technological determinism	Institutional lag theory
Technology-institution relationship	Technology evolves autonomously; institutions adapt passively	Technology breaks through first, and institutions lag behind in catching up
Risk attribution	Technology is not advanced enough, and algorithms are not precise enough	Regulations are not perfect enough, and institutions are not timely enough
Governance strategy	Technology investment and system upgrades should be continuously increased.	The legislative process and institutional construction should be accelerated
Underlying premise	Technology is neutral and efficiency is paramount	Institutions can eventually catch up with technology

A deeper analysis shows that both paradigms share a fundamental premise that technology and institutions are separate domains, and neither has touched upon their mutually constitutive relationship. Qiu[17] pointed out that the theoretical development of technology and organization research has evolved from technology-centered theory to context-centered theory, and then to society-centered theory. Based on this, this paper argues that the embedding of intelligent technology in public health governance should be understood as a mutually constitutive process between technology and institutions, rather than a oneway relationship of determination or being determined.

2.2 From "dual effects" to "structural mismatch": the theoretical integration path of this paper In order to transcend the above binary opposition, this paper puts forward an analytical framework of "dual effects-structural mismatch". "Dual effects" is a descriptive generalization of the consequences of technological embedding: technology produces both empowering effects and tension effects (fairness controversies, transparency dilemmas, and participation imbalances). "Structural mismatch" is an explanatory concept for the roots of tension effects, pointing to the institutional rupture between the technological system and the governance system at the level of underlying logic.

The core judgment of this paper is that the problem is not that technology is too strong or institutions are too weak, but rather that the underlying logics of the two are misaligned. Specifically, one pursues computational optimization, whereas the other pursues value legitimacy, and there is a lack of institutional interfaces to constrain the former within the latter. Structural mismatch can be defined from three dimensions. First, the technological system is oriented toward efficiency maximization and closed-loop automation, while public health governance is based on core values such as fair distribution, transparency, explainability, and open participation. Second, the tension between the two logics is not a temporary technological flaw, but results from the lack of effective transformation and buffering mechanisms at the institutional design level. Third, this mismatch is not a question of technology being "good" or "bad", but a problem of lacking institutional interfaces for value embedding when technology is embedded into governance. Chen[18] pointed out that there is a complex adaptive relationship among the technology orientation, institution orientation, and people orientation, requiring a dynamic balance between efficiency, norms, and values. Jia *et al.* [19] put forward a framework for classified governance of algorithms from the two dimensions of technological embedding and value orientation. Bao *et al.* [20] emphasized that digital government governance involves a deep transformation of institutional structures and governance logics.

This framework shifts the analytical focus from the normative debate of "whether technology is advanced" to the explanatory question of "how technological logic and governance logic can be effectively aligned at the institutional level". Based on this, the following sections of this paper will develop institutional responses from three dimensions. In the technology governance dimension, the focus is on building algorithmic explainability to address the tension between the "black box of algorithms" and decisionmaking transparency. In the institutional construction dimension, the goal is to clarify the boundaries of rights and responsibilities and to establish institutional norms that run through the entire process of technology design, data collection, and decisionmaking application. In the social collaboration dimension, the aim is to explore institutionalized channels for multi-stakeholder participation in governance, addressing the structural deficiency of insufficient public participation in technology application. These three dimensions together constitute a systematic analysis path from the diagnosis of "structural mismatch" to the formulation of institutional adaptation schemes.

3 The logic of empowerment: three mechanisms by which intelligent technology reshapes the effectiveness of public health governance

The primary effect of embedding intelligent technology in public health governance is the systematic improvement of governance effectiveness. This chapter reveals how technological tools interact with governance structures and promote a paradigm shift in risk identification, decision support, and resource allocation from the three dimensions of datadriven approaches, intelligent analysis, and process reengineering. It should be noted that "empowerment" is not an inevitable outcome of the unilateral action of technology, but a conditional product arising from the coupling of technological characteristics and institutional arrangements. This analysis will set the stage for the subsequent discussion on "tension".

3.1 Data-driven approaches: the precision transformation of monitoring and early warning Traditional public health monitoring systems rely on hierarchical reporting mechanisms, characterized by "passive reporting"[21]. This model has inherent limitations. On the one hand, there is a time delay from case detection to information reporting, which may cause the window period for risk intervention to be missed. On the other hand, the statistical logic of sampling inference makes it difficult to capture abnormal signals in nonlinear transmission. Intelligent technology shifts risk identification from sampling inference to fullscale calculation by integrating multisource heterogeneous data such as electronic medical records, population mobility trajectories, and environmental monitoring sensors, achieving a paradigm shift from "passive reporting" to "active sensing"[22]. Zhang *et al.* [22] pointed out that the new generation of information technology has greatly reduced the time threshold of early warning response through realtime collection and intelligent analysis of total data.

The health code system during the COVID19 pandemic is a typical practice. An infectious disease surveillance system in a certain city constructed a multidimensional monitoring network covering "individual-community-city" by integrating electronic medical records from medical institutions, entryandexit records at transportation hubs, and community grid screening information. When the system identifies an abnormal clustering pattern of cases, it can automatically generate a risk warning within a few hours and push it to the disease control department, achieving a qualitative leap in the timeliness of early warning[22]. However, data-driven does not mean data-determined. Yu *et al.* [23] emphasized that the effectiveness of technological empowerment depends on the institutional structure into which it is embedded. Data quality, source credibility, and the applicable boundaries of algorithmic models all rely on quality assurance mechanisms at the institutional level. In the absence of standardized constraints on data collection and routine reviews of algorithmic bias, "data-driven" may devolve into "data-misleading". Therefore, effective institutional guarantees for the data infrastructure are a prerequisite for achieving technological empowerment[24].

3.2 Intelligent analysis: the computational upgrade of decision support Based on the information richness achieved through the data-driven approach, intelligent analysis further transforms information into knowledge products usable for decision-making. The application of machine learning models in areas such as resource demand forecasting, transmission dynamics simulation, and high-risk population identification is gradually shifting public health decision-making from a model relying on expert experience to a hybrid model of "empirical judgment + algorithm assistance"[25]. Meng[4] pointed out that the core of government digital transformation lies in the two-way interaction between technological empowerment and institutional guarantees, and lgorithmic tools do not replace human judgment, but rather expand the cognitive boundaries of decision-makers.

It is necessary to strictly distinguish between the concepts of "decision support" and "decision substitution". The intelligent analysis discussed in this paper belongs to the former, that is, algorithmic models provide probabilistic predictions and scenario simulation results for decision-makers' reference, rather than directly outputting binding administrative decisions. Based on complex adaptive systems theory, Suo *et al.* [26] pointed out that human AI collaboration is a key pathway for the evolution of digital government, and the value of algorithmic systems lies in forming a complementary division of labor with administrative staff. In this sense, the efficiency of intelligent analysis comes not only from algorithm accuracy, but also from the structural position in which it is embedded in the decision-making process—that is, in what form, at what point, and through what procedures the algorithm output enters the cognitive framework of decision-makers. Gao *et al.* [25] found in their analysis of digital transformation of "medical service and basic insurance and drug management synergy" that the real advantage of algorithm-assisted decision-making lies in providing support for complex resource allocation problems through multi-scenario simulation and quantitative comparison. Only when algorithm output interacts effectively with the careful judgment of professionals can the governance effectiveness of technological empowerment be fully unleashed.

3.3 Process reengineering: the collaborative restructuring of resource allocation The technical capabilities of data-driven approaches and intelligent analysis ultimately need to be transformed into actual governance effectiveness through organizational process reengineering. Zhu[27] proposed the theory of "holistic governance", which points out that traditional bureaucracy faces the structural dilemma of departmental fragmentation and information silos, and information technology provides a key operational carrier for breaking down organizational barriers. Huang *et al.* [28] pointed out that the core of digitally empowering governance collaboration lies in reducing the transaction costs of crossdepartmental coordination through the connectivity function of technological platforms, thereby improving overall governance effectiveness. In public health emergency scenarios, intelligent dispatching systems achieve cross-level and cross-sectoral coordination of resources such as epidemic prevention supplies, hospital beds, and personnel deployment.

Taking the allocation of supplies during epidemic prevention as an example, under the traditional model, the procurement, storage, and distribution of epidemic prevention supplies are managed segmentally by different departments, resulting in high coordination costs and slow response speeds. The intelligent dispatching platform enables full-chain visual tracking and dynamic allocation of supplies from central warehouses to frontline terminals by aggregating inventory data and demand forecasts from medical institutions at all levels in real time, significantly shortening the response cycle[29]. However, the same process reengineering may also be accompanied by potential risks. The establishment of cross-departmental collaboration platforms is often accompanied by the decentralization of decision-making nodes, and in the absence of clear responsibility definition and accountability mechanisms, process optimization may lead to the blurring and fragmentation of responsibility attribution[23].

In summary, through the three mechanisms of data-driven approaches, intelligent analysis, and process reengineering, intelligent technology has reshaped the effectiveness boundaries of public health governance at the levels of information infrastructure, cognitive capacity, and organizational structure. However, on the flip side of the empowerment logic are the governance tension deriving from technological embedding. The expansion of technological capacity not only improves efficiency, but also poses new adaptation requirements for the existing institutional framework.

4 The emergence of tension: risk alienation caused by technological embedding

The empowerment of public health governance by intelligent technology is not a one-dimensional linear progression. As data collection becomes more intensive, algorithmic decision-making more widespread, and the degree of automation higher, a series of deep-seated tensions also emerge. These risks are not external add-ons or "side effects" of technology, but are endogenously produced by the embedding of technology into governance structures, exhibiting systemic, gradual, and structural characteristics.

4.1 Privacy erosion: data-driven monitoring and the blurring of public-private boundaries The digital transformation of public health governance is based on large-scale data collection. Zha[30] pointed out that the health code, as an automated risk assessment tool for individual epidemic risk, is essentially a comprehensive digital collection and real-time dynamic evaluation of personal health information. Zhang *et al.* [31] further revealed that the health code effectively reduces social complexity through a threefold mechanism of "data-driven identification-categorized control-dynamic tracking", and this reduction process comes at the cost of the concession of personal privacy. Chen's study showed that there is a persistent tension between the sharing and utilization of health and medical data and the protection of personal information, and issues such as excessively broad data collection scope, multiple processing purposes, and unclear storage periods are common in public health scenarios[32]. Man[34] argued that the governance of health and medical big data involves not only individual privacy, but also the protection of health rights and interests at the group level from the perspective of the right to health, and secondary use and extended storage of data may pose a potential threat to the realization of the right to health[33]. Guo *et al.* [34] further emphasized that data governance in the field of public health faces multiple security risks, such as data breaches, unauthorized access, and cross-domain abuse, and that current institutional constraints remain insufficient.

This paper argues that privacy erosion in the field of public health has a gradual character. Each data collection request seems justified. Epidemiological investigations require trajectory information, vaccination requires identity verification, and health monitoring requires physical data. However, as these seemingly reasonable concessions accumulate, individuals gradually lose full control over their own health data, and the public-private boundary dissolves incrementally. This logic paradoxically echoes the empowerment logic: the deeper the data-driven empowerment, the stronger the systemic nature of privacy risks.

4.2 Algorithmic bias: unfair distribution under the illusion of technological neutrality Algorithms are often endowed with an aura of "objective neutrality", while more and more studies show that by learning from historical data, algorithms often solidify or even amplify existing social biases. Zhang[35] pointed out that the public nature of algorithmic governance requires algorithms not only to have technical effectiveness, but also to embody the public values of fairness and justice. However, in reality, algorithms often degenerate into technical tools that favor specific interests. Kuang's study on automated decisionmaking in social assistance revealed three typical types of algorithmic bias: dataset construction bias, algorithm design and operation bias, and algorithm transparency and explainability bias[36]. Du[37] systematically analyzed the risk manifestations of algorithmic power embedded in the field of public policy from the three dimensions of public value misalignment, multiagent problems within organizations, and the exercise of administrative discretion.

This paper introduces an important conceptual distinction: statistical bias versus institutional bias. Statistical bias originates from imbalanced data samples or flaws in algorithmic models, and is a type of bias that can be corrected at the technical level. Institutional bias is deeper. It refers to algorithms automating and obscuring existing unfair rules in society, thereby giving bias legitimacy under the guise of "technological neutrality". In Eubanks' empirical research on welfare, housing, and child protection in the United States, she found that automated decisionmaking systems disproportionately target and penalize poor and marginalized communities, systematically exacerbating social inequality[38]. Based on this, this paper makes a key judgment: algorithmic bias is not a failure of algorithms, but rather the successful execution of biased institutional logic by algorithms. In the context of public health governance, this means that algorithm-based resource allocation systems may systematically place marginalized groups at a disadvantage, not because the algorithm "made a mistake", but because the algorithm "faithfully" replicates the structural inequalities embedded in historical data.

4.3 Power shift: the substitution of professional autonomy by automated decision-making Automated decision-making not only changes governance tools, but also reshapes power relations among governance actors. Hou and Zhang[39] pointed out that the legal nature of algorithmic automated decisionmaking lies between "tool" and "quasi-subject", and the inexplicability of its decision-making process and the ambiguity of responsibility attribution pose fundamental challenges to the rule of law in administration. Zhang[40] analyzed that algorithmic automated decision-making has a systematic impact on the administrative transparency, public participation, and justification system in the administrative due process.

In the field of public health, when algorithm recommendations are tacitly accepted as the "optimal solution", the discretionary space of frontline professionals quietly narrows. Alon-Barkat *et al.*'s empirical study revealed patterns of "automation bias" and "selective compliance" with AI recommendations in public sector decision-making[41]. Selten *et al.*'s study of streetlevel bureaucrats' AI usage further found that when AI recommendations align with professional judgment, frontline workers tend to adopt the algorithm recommendations without scrutiny, creating a psychological confirmation effect of "just as I thought"[42]. This paper terms this phenomenon decision-anchoring effect: the algorithm recommendation becomes a psychological anchor for decision-making, and professionals may overlook key heterogeneous information in their own experiential judgment due to over-reliance on the algorithm.

Xiao[43] pointed out that responsibility attribution in algorithmic administration exhibits a "distributed" character, making traditional centralized accountability logic difficult to apply. It means that when algorithmic decision-making goes wrong, responsibility diffuses among data providers, algorithm developers, and decision executors, and frontline professionals lose full discretion while also lacking clear responsibility attribution. This paper argues that the same technical mechanisms, intelligent analysis and risk prediction, are both empowering tools and potential eroders of professional autonomy. Technical authority quietly replaces professional authority, a process often obscured by the narrative of "efficiency improvement".

5 Deep roots: the structural mismatch between the expansion of technical rationality and the adherence to public values

The previous sections have revealed the empowering effects and tension manifestations produced by the embedding of intelligent technology in public health governance. However, a more fundamental question remains to be answered: why can the same technological system both significantly improve governance effectiveness and simultaneously cause privacy erosion, algorithmic bias, and power shifts? This chapter argues that these tensions are rooted in the structural mismatch between the technological system's pursuit of efficiency optimization and public governance's value logic of fairness, transparency, and accountability.

5.1 The inherent tensions between the efficiency-first logic and fairness, transparency, and accountability The core operational logic of intelligent technology is optimization, that is, seeking the efficiency-maximizing solution under given constraints through algorithmic models[37]. However, the essence of public governance is not a purely technical optimization problem, but a process of balancing multiple values, where fair distribution, procedural transparency, and traceable accountability constitute irreducible core dimensions[35]. When the efficiency logic is embedded in public health governance without mediation, the tension between the two is activated.

The deep mechanism of the tension can be summarized as the "value commensurability trap". The technological system tends to transform all governance problems into quantifiable indicators, while values that are difficult to fully quantify, such as the health dignity of vulnerable groups and the right to informed consent, are systematically down-weighted in indicator weighting[44]. Guo[45] pointed out that technical rationality has a deep failure when facing complex public affairs, and the root cause lies in the inability of instrumental rationality to commensurate the multi-dimensional connotations of public values. Taking the protection of vulnerable groups in public health as an example, if algorithm-driven resource allocation takes infection risk and cost-benefit as optimization objectives, its "efficiency-optimal solution" tends to concentrate resources in densely populated areas, while potentially overlooking the health needs of remote areas, the elderly, and the floating population—groups that are marginalized in the model due to "data sparsity". The study of Bao *et al.*[46] on public value governance also showed that if performance governance follows only the efficiency orientation, it will inevitably lead to the marginalization of public values. Chang *et al.*[47] pointed out that algorithm governance oriented toward public value creation must go beyond the technical efficiency orientation and actively embed fairness constraints. Ma *et al.*[48] revealed that technological governance may lead to the instrumentalization of governance values, with normative values such as fairness and transparency being degraded into configurable parameters. Han[14] revealed the "illusion of neutrality" of technological governance, which further indicates that the efficiencyfirst logic itself is a value choice. The deeper the embedding of technology into governance processes, the more significant the squeeze of the efficiency logic on unquantifiable public values.

5.2 The temporal disconnect between lagging institutional supply and the dynamic demands of intelligent governance

While Section **5.1** revealed the logical tension between technological rationality and public values, the lag in institutional supply constitutes the organizational condition for the persistence of the tension. intelligent technology iterates on a monthly basis, while institutional change including legislative revisions, standard setting and process restructuring occurs on a yearly basis[49]. This speed differential leads governance into a reactive cycle of "technology first-problem exposure-institutional repair". Wang[50] found that when a technological system is detached from the adaptive conditions of grassroots governance ethics, systematic "technological inaccuracy" occurs. Huang *et al.*[15] also pointed out that technological governance has structural limits at the level of institutional adaptation.

The deeper issue is that current institutional design lacks mechanisms for "proactive ethical embedding". Qiu's study showed that there is a complex mutually constitutive relationship between information technology and the institutional environment; and if institutions cannot proactively respond to the ethical implications of technological embedding, they can only reactively follow in the wake of governance crises[17]. In the field of public health, the health code and epidemiological investigation systems were rapidly deployed under emergency conditions, while detailed data protection rules and algorithm audit standards were absent for a long time. This path dependence of "construction first, regulation later" leads to the spontaneous expansion of technology systems without value constraints, and remedial measures are taken after problems are exposed. At this point, the governance structure embedded in technology has become more rigid, and the cost of correction has sharply increased.

To break this cycle, it is necessary to shift from "institutional rigidity" to "institutional resilience". Institutional resilience refers not only to the ability of institutions to recover from shocks, but also emphasizes their adaptability and robustness in the face of rapid technological evolution[51]. Rong *et al.*[52] constructed a resilient governance framework which indicates that a robust institutional system must maintain order stability while retaining flexible space for timely adaptation. Yu *et al.*[51] further proposed that institutional resilience, following the principle of risk prevention, is a key mechanism for dealing with uncertainty. For smart public health governance, institutional resilience means that laws and regulations should not exhaustively specify technical details, but should establish principled value anchors and reserve institutional interfaces for technological evolution. Meanwhile, through procedural arrangements such as algorithm impact assessments and ethical reviews, ethical considerations should be placed before technology deployment, transforming institutions from followers to guides.

6 Institutional adaptation: design of a three-dimensional collaborative framework

The analysis above shows that the tension effects produced by the embedding of intelligent technology in public health governance are not rooted in functional flaws of the technology itself, but in the structural mismatch between technological logic and governance logic, as technology pursues computational optimization, whereas governance pursues value legitimacy, and there is a lack of effective institutional interfaces between the two. The two dominant paradigms in existing research, technological determinism and institutional lag theory, fail precisely because they treat technology and institutions as separate entities. Based on this, this paper proposes a three-dimensional collaborative framework of "technology governance-institutional construction-social collaboration", addressing the three institutional ruptures of missing explainability, blurred boundaries of rights and responsibilities, and participation imbalance.

6.1 Technology governance dimension: embedding explainable algorithms into the technological foundation To address the conflict between the algorithm black box and the requirements of governance transparency, it is necessary to embed explainability mechanisms at the level of the technological foundation. Wang[53] pointed out that algorithm transparency has multiple dimensions, with different dimensions corresponding to different governance objectives and institutional costs. The study of Duan *et al.* [54] showed that explainability significantly affects the adoption preference of grassroots civil servants for algorithm decision-making. Guo[55] further proposed that AI governance is undergoing a paradigm shift from "explainability" to "trustworthiness". The above studies show that explainability is not only a technical optimization goal, but also an institutional bridge connecting the technological system and the governance system.

This paper proposes a "tiered explanation" mechanism. Specifically, for critical decisions that directly affect citizens' rights and interests such as high-risk population designation and the application of isolation measures, causal explanations should be provided, clarifying the key factors and their weights. For supporting decisions such as epidemiological analysis and trend prediction, feature attribution should be provided, revealing the main variables influencing the output. Zhang *et al.* [56] pointed out that tiered explanation helps strike a balance between protecting trade secrets and meeting the public's need for information. The "counterfactual explanation" method proposed by Wachter *et al.* provides a technical pathway for this: without opening the algorithm black box, it provides an understandable reason for the decision to those affected by showing how changes in conditions affect the output[57].

This mechanism has inherent institutional connectivity with Article 24 of China's *Personal Information Protection Law*, which provides the "right to explanation of automated decisions". Yang *et al.* [58] pointed out that this article grants individuals the right to informed consent for automated decisions. However, algorithm decisions in public health scenarios involve group and public interests, requiring a moderate institutional extension of the individual right to explanation. Based on this, this paper proposes the concept of the "right to explanation of public health algorithms": in the event of a public health emergency, affected individuals or their representatives have the right to question the underlying logic and data sources of algorithmic decisions, and the deploying institution has an obligation to provide a substantive response within a reasonable timeframe. Explanation does not require full disclosure of the algorithm code, but should ensure that affected individuals understand "why I was judged as such".

6.2 Institutional construction dimension: a resilient regulatory system delineating the boundaries of rights and responsibilities To address the temporal disconnect between lagging institutional supply and the dynamic demands of technological governance, it is necessary to build a resilient regulatory system that has both rigid constraints and elastic adaptability. Rong *et al.* [52] pointed out that resilient governance requires the institutional system to have robustness, flexibility, and adaptability simultaneously. This paper introduces this concept into the field of algorithm governance and proposes a threelayer structure of resilient regulations.

Bottom-line rigidity refers to inviolable value bottom lines. In public health algorithm governance, bottom-line rigidity is embodied in the prohibition of algorithmic discrimination based on sensitive attributes, the establishment of the "minimum necessary" principle for data collection, and the guarantee of a final human review in critical decisions. Zeng *et al.* [59] pointed out that the European Union's *Artificial Intelligence Act* classifies riskscoring algorithms in the field of public health as "high-risk" and imposes strict transparency and human oversight obligations, providing a reference for the design of bottomline rigidity.

Mid-level flexibility refers to dynamic adjustment mechanisms for technical standards. Zhang[60] proposed an assessment framework of "full-cycle coverage, closed-loop linkage", allowing institutional norms to adjust dynamically with technological evolution. Gao[61] advocated for a tiered management of algorithmic systems based on personal rights types and the available discretionary space, classifying them into low, medium, and high-risk categories. Li[62] proposed a "two-step" approach for algorithm impact assessment in China: in the short term, primarily industry self-regulation and administrative guidance, and in the long term, transitioning to legal enforcement. The above studies collectively indicate that mid-level flexibility is not about deregulation, but about achieving "precision regulation" through tiered classification.

Toplevel participation refers to institutional channels for stakeholder participation in rule-making. This paper advocates establishing algorithm impact assessment (AIA) as a legally mandatory obligation before the deployment of public health algorithms, covering procedures such as impact identification, bias assessment, risk mitigation, and public disclosure. The European Union's *Artificial Intelligence Act* has already pioneered a conformity assessment system[63], and China's *Administrative Provisions on Algorithm Recommendations for Internet Information Services* provides a regulatory foundation for the localization of AIA[64].

Based on this, this paper proposes the regulatory concept of a "responsibility allocation matrix". In specific, for systemic deviations caused by data bias, the data collectors and model trainers bear primary responsibility. For applicability errors resulting from improper deployment, the deploying institution bears primary responsibility. For individual errors resulting from operational mistakes, the user bears corresponding responsibility. And for risk escalation resulting from regulatory absence, the regulatory agency bears accountability for the consequences. This matrix helps resolve the current accountability dilemma of algorithm decisions where "everyone is responsible, but no one is held accountable".

6.3 Social collaboration dimension: multi-stakeholder co-governance reshaping the decision-making ecosystem To address the imbalance in public participation caused by automated decision-making, it is necessary to introduce multi-stakeholder co-governance mechanisms. The SFIC collaborative governance model proposed by Ansell *et al.* points out that successful collaborative governance depends on the coordination of four core elements: starting conditions, facilitative leadership, institutional design, and collaborative processes[65]. Li[66] emphasized that the cooperation and interaction of multiple stakeholders are the institutional foundation for integrating resources and achieving common goals.

This paper proposes the concept of "algorithm participatory governance", with the core mechanism being the establishment of a Public Health Algorithm Advisory Committee, involving patient representatives, ethicists, data scientists, legal experts, and grassroots public health workers in algorithm governance. Huang *et al.* [67] pointed out that shifting from transparency-dependent governance to participatory governance that leverages human agency is a key pathway to achieving good algorithmic governance. Zhang *et al.* [68] argued for the logic of participatory algorithm governance: public participation does not replace professional decision-making, but enhances governance legitimacy by increasing the reflexivity of decisions[68].

The functional positioning of this committee includes: conducting pre-deployment ethical reviews of major algorithmic systems; providing expert opinions on value trade-offs in algorithm deployment; conducting ongoing effect assessments of deployed systems; and receiving public objections to algorithm decisions and organizing independent reviews. Wang *et al.* [69] pointed out that digital social governance should adhere to the principle of risk sharing, with multiple stakeholders converging on the same platform to achieve public value. Rong[70] emphasized that multi-stakeholder collaboration is the core mechanism of public health governance.

It must be emphasized that multi-stakeholder co-governance does not undermine the technical content of professional decision-making, but rather increases the legitimacy and reflexivity of decisions. Meng[4] pointed out that state governance in the digital era should advocate for state-society collaborative governance, driven by the two-way transformation of technology empowerment and technology rights empowerment. What collaborative governance pursues is a dynamic balance among technological efficiency, institutional norms, and public values, which is the core purpose of the three-dimensional collaborative framework.

To sum up, the technology governance dimension provides the tool foundation, the institutional construction dimension provides normative guarantees, and the social collaboration dimension provides the source of legitimacy. The three dimensions support each other, cooperate with each other, and jointly respond to the structural mismatch, providing an institutional solution for moving toward a new pattern of public health governance compatible with "efficiency-resilience".

7 Conclusions: toward efficiency-resilience compatible smart public health governance

This paper takes the dual effects of embedding intelligent technology in public health governance as its core concern, and examines the mutually constitutive relationship between technological logic and governance logic through the "dual effects-structural mismatch" framework.

At the empowerment level, intelligent technology significantly improves the effectiveness of public health governance through data-driven precision monitoring, computational decision-making via intelligent analysis, and collaborative configuration via process reengineering. However, the same technological system also endogenously produces three tensions: privacy erosion, algorithmic bias, and power shifts. This paper finds that the deep root of these tensions lies in the structural mismatch between the underlying logic of the technological system pursuing efficiency optimization and the value logic of public governance adhering to fairness, transparency, and accountability. One pursues computational optimization, whereas the other pursues value legitimacy, and there is a lack of effective institutional interfaces between them.

At the theoretical level, this paper achieves two breakthroughs. First, it goes beyond the binary opposition of technological determinism and institutional lag theory, proposing the concept of "structural mismatch" and shifting the analytical focus from "whether technology is advanced" to "how technological logic and governance logic can be aligned at the institutional level". Second, it constructs a threedimensional adaptive framework of "technology governance-institutional construction-social collaboration", providing an integrated analytical perspective for intelligent governance.

At the practical level, this paper offers three insights. First, the ethical legislation of public health algorithms should be accelerated, and algorithm impact assessment should be established as a legally mandatory obligation. Second, a tiered explanation mechanism and a right to explanation of public health algorithms need to be established. Third, multiple governance actors should be cultivated, and a Public Health Algorithm Advisory Committee ought to be established.

As a theoretical framework, this paper awaits testing by case studies and empirical research. Future work may include transnational comparative analyses and evaluations of the governance effectiveness of the framework.

Efficiency is the promise of technology, while resilience is the answer of institutions. Only by constraining technological rationality within the institutional track of public values can smart public health truly stand firm and go far.

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