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Digital Health Regulation and Hospital Management in the Era of Telemedicine: Digital Governance, Regulatory Participation, and Leadership Challenges

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Abstract

Telemedicine has become a part of care within the hospital; digital governance and regulatory involvement have become major factors. This study examined associations between hospital digital-network participation, organizational characteristics, Trusted Exchange Framework and Common Agreement (TEFCA) participation, and Medicare telehealth utilization. Four public datasets were used, and the rate of linkage was above 97% for 3,380 hospitals. A Digital Governance Capability Index (DGCI) was developed using four indicators and assessed through principal component analysis and sensitivity testing. Multivariable logistic regression examined TEFCA participation, while state-level ecological regression and exploration of Random Forest and SHAP analyses assessed telehealth utilization. The strongest association with TEFCA participation was with national network participation (OR = 3.25, 95% CI 2.64–4.00), followed by vendor network participation (OR = 2.25) and health information organization participation (OR = 1.49). Proprietary ownership positively contributed to participation; Critical Access Hospital status was negatively associated. Structural robustness was supported by the DGCI's strong values (r = .998). Utilization of telehealth was positively associated with DGCI at the state level (b = .0032, p = .001), and rural utilization was found to be lower than urban utilization (9.6% versus 14.1%). The results point to significant mechanisms related to regulatory participation, telehealth adoption, digital governance, and organizational leadership, but they do not prove causality.

Keywords: digital health regulation, hospital management, TEFCA, interoperability, telemedicine, digital governance capability.

1. Introduction

1.1 Digital Transformation and the Institutionalisation of Telemedicine

Hospital care in the United States has undergone a sustained shift toward digitally mediated delivery, encompassing telemedicine and virtual care, interoperable exchange of electronic health information, and participation in expanding digital platforms and networks. The COVID-19 pandemic accelerated this shift, prompting international consortia to document the rapid, emergency-driven deployment of telehealth services across health systems (Bhaskar et al., 2020). What followed, however, was not a simple reversion to pre-pandemic patterns. National utilisation data show a sharp decline from the pandemic-era peak followed by stabilisation at a materially higher baseline than before 2020, prompting sustained scholarly interest in whether this represents a durable transition rather than a temporary artefact of emergency policy (Ndwabe et al., 2024). Beneficiary-level evidence further complicates any narrative that treats 2020 as a

clean discontinuity: rural Medicare telemedicine use was already increasing throughout the preceding decade, suggesting that the pandemic accelerated an existing trajectory rather than creating an entirely new one (Barnett et al., 2021). The central managerial question facing hospitals is therefore no longer simply whether to adopt telemedicine, but whether the organisational and governance capabilities hospitals possess are sufficient to sustain digitally mediated care within an increasingly complex regulatory and interoperability environment.

1.2 Digital Health Regulation as a Hospital-Management Challenge

The regulatory environment surrounding digital health has grown correspondingly complex. Federal interoperability policy has evolved from the Meaningful Use incentives established under the Health Information Technology for Economic and Clinical Health (HITECH) Act toward the current Promoting Interoperability framework, which places increasing emphasis on certified health information technology, electronic information exchange, and interoperability (Blumenthal, 2011; Blumenthal & Tavenner, 2010; Services, 2026). Layered atop these requirements is the Trusted Exchange Framework and Common Agreement (TEFCA), authorised under the 21st Century Cures Act, which establishes a national governance structure intended to connect fragmented health information exchanges into a single interoperable system (Assistant Secretary for Technology Policy/Office of the National Coordinator for Health Information, 2024a). Privacy, security, and accountability provisions accompany this architecture, alongside a growing reliance on national and vendor-mediated exchange networks that sit between individual hospitals and this national governance layer. These requirements are not merely technical or legal formalities to be delegated to information-technology departments. Each involves managerial decisions about capital investment, organisational coordination, data governance, compliance risk, and strategic prioritisation, decisions that determine whether a hospital can participate meaningfully in interoperability structures that regulators increasingly treat as baseline expectations rather than optional enhancements.

1.3 Leadership Challenges in the Telemedicine Era

Because the dataset underlying this study does not directly measure executive behaviour or leadership style, leadership is positioned here as an organisational challenge to be explained rather than a variable to be measured. Four such challenges recur across the literature. Regulatory adaptability concerns a hospital's capacity to adjust to an evolving governance landscape, exemplified by TEFCA's phased rollout and the demands it places on data-exchange infrastructure. Interoperability and infrastructure investment concerns the capital and technical resources required to establish and maintain the network relationships, HIO participation, national-network participation, and vendor-network participation, which underpin regulatory readiness. Organisational digital capability concerns the broader institutional capacity to sense, seize, and reconfigure resources in response to a changing digital-governance environment, a capacity that recent concept-analysis and case-study work identifies as unevenly distributed and only loosely tied to formal leadership training (Laukka et al., 2022; Tanniru et al., 2018). Equitable and sustainable telemedicine delivery concerns whether the benefits of digital transformation extend evenly across hospitals and the populations they serve, rather than concentrating among already well-resourced institutions. Together, these four challenges frame telemedicine leadership not as a matter of individual style but as an organisational and structural challenge that can be examined through observable patterns of digital capability, regulatory participation, and organisational readiness.

1.4 Research Problem

Much of the existing literature treats telemedicine utilisation, interoperability, digital-health regulation,

and hospital digital transformation as largely separate research streams, each with its own methods, data sources, and disciplinary conventions. Less is known about how hospital-level digital-governance capabilities and organisational characteristics jointly relate to participation in emerging regulatory interoperability structures such as TEFCA, and whether broader hospital digital-governance environments are associated with sustained telemedicine utilisation at the population level. This separation leaves an important managerial and policy question underexamined: whether hospital digital-exchange capability is associated with participation in emerging regulatory structures and whether, at the broader system level, states characterised by greater aggregate hospital digital-governance capability also exhibit higher telehealth utilisation (Everson et al., 2023; Johannes et al., 2023).

1.5 Research Gap and Novelty

The novelty of this study lies in integrating previously separate empirical traditions rather than in the use of any single public dataset. Hospital-level data on digital-network participation, Promoting Interoperability performance, and organisational characteristics are linked using standardised hospital identifiers to construct a substantially complete hospital-level analytic file. These data are then integrated analytically with Medicare Telehealth Trends at the state level, enabling hospital digital-governance capability to be examined alongside population-level telehealth utilisation. From the hospital-level indicators, a Digital Governance Capability Index (DGCI) is constructed and evaluated for structural robustness using both a data-driven method, principal component analysis, and a component-sensitivity method, leave-one-component-out analysis, an approach that has received limited attention in the existing hospital digital-capability literature. TEFCA participation is then modelled directly against digital-network participation and hospital organisational characteristics, a relationship that has received limited direct empirical examination because prior interoperability research has generally focused on broad interoperability engagement rather than participation in this specific national governance structure (Sherer et al., 2016). Finally, aggregated hospital digital-governance capability is linked to state-level Medicare telehealth utilisation, and the principal regression findings are compared with a supplementary machine-learning analysis as an exploratory robustness assessment.

1.6 Aim and Objectives

The aim of this study is to examine hospital-level relationships between digital-exchange capability, organisational characteristics, and regulatory participation; to assess the state-level association between aggregate hospital digital-governance capability and Medicare telehealth utilisation; and to identify the associated strategic leadership challenges for hospital management. This aim is pursued through the following objectives:

1. To assess the distribution of hospital digital-network and governance capabilities.
2. To develop and evaluate the structural robustness of a hospital-level Digital Governance Capability Index.
3. To examine whether HIO, national-network, and vendor-network participation are associated with TEFCA participation.
4. To examine whether hospital organisational characteristics are independently associated with TEFCA participation after accounting for digital-network capability.
5. To examine temporal and geographic patterns in Medicare telehealth utilisation, with particular attention to rural-urban differences.
6. To assess the ecological association between state-level hospital digital-governance capability and telehealth utilisation.

7. To evaluate the implications of these findings for hospital leadership and digital-health regulation.

1.7 Research Questions and Hypotheses

Four hypotheses follow directly from the research problem and gap identified above. H1 proposes that hospital participation in digital exchange networks, encompassing HIO, national-network, and vendor-network participation, is positively associated with TEFCA participation. H2 proposes that hospital organisational characteristics are significantly associated with TEFCA participation after accounting for digital-network capability. H3 proposes that greater state-level hospital digital-governance capability is positively associated with Medicare telehealth utilisation. H4 proposes that the DGCI will demonstrate structural robustness across alternative construction and component-sensitivity analyses, while the associations between digital-network participation and TEFCA participation will remain substantively consistent across extended model specifications. Leadership is deliberately excluded from formal hypothesis testing, since the underlying data do not measure individual leadership behaviour; instead, leadership is treated throughout as the organisational mechanism through which the tested associations are enacted, consistent with the theoretical framing developed in the following section.

2. Literature Review and Conceptual Framework

2.1 Digital Health and Telemedicine Transformation

The institutionalisation of telemedicine within hospital care has moved through distinct phases that the literature has documented largely in isolation from one another. Early accounts framed telemedicine primarily as an emergency substitute for in-person care, with international consortia cataloguing rapid deployment across health systems during the acute phase of the COVID-19 pandemic (Bhaskar et al., 2020). Subsequent research shifted toward characterising the scale of the post-pandemic decline and the extent to which utilisation would settle into a durable, if smaller, component of routine care (Ndwabe et al., 2024). Beneficiary-level claims analyses covering the 2010 to 2019 period established that rural telemedicine use was already rising before the pandemic, which complicates any narrative that treats 2020 as a clean discontinuity rather than an acceleration of a pre-existing trajectory (Barnett et al., 2021).

A recurring limitation across this literature is that utilisation trends are typically analysed as an outcome of clinical demand, policy waivers, or patient preference, with comparatively little attention paid to whether the hospitals delivering that care possess the underlying digital-governance infrastructure to sustain it. Studies of utilisation trajectories and studies of hospital interoperability capacity have, until recently, proceeded along separate empirical tracks. This separation is analytically consequential, because sustained telemedicine delivery presupposes not only patient willingness and regulatory permission but also a hospital's capacity to exchange, verify, and act on external clinical information, an organisational capability that is rarely measured in utilisation-focused studies.

2.2 Digital Health Regulation as a Hospital-Management Challenge

Digital health regulation in the United States has developed cumulatively rather than through a single coordinated instrument. The Health Information Technology for Economic and Clinical Health (HITECH) Act established financial incentives for the adoption and meaningful use of certified electronic health record technology, while subsequent policy development evolved these requirements into the Promoting Interoperability framework (Blumenthal, 2011; Blumenthal & Tavenner, 2010). This regulatory architecture treated interoperability primarily as a certification and reporting obligation, a framing that persists in much of the compliance literature. Sherer et al. (2016) offer a more critical reading, arguing that adoption decisions are better understood as responses to coercive, mimetic, and normative institutional

pressures than as straightforward technical compliance, a distinction with direct consequences for how regulatory participation should be modelled empirically.

Privacy, security, and accountability provisions layered onto this architecture over time, but the management literature has been slower to treat these requirements as strategic variables rather than legal constraints. Where regulation is reduced to a checklist of certification criteria, the underlying managerial question, namely whether a hospital's governance capability is sufficient to operate safely within an increasingly interconnected information environment, tends to be obscured rather than examined directly.

2.3 Interoperability and TEFCA

The Trusted Exchange Framework and Common Agreement (TEFCA), authorised under the 21st Century Cures Act and finalised through subsequent rulemaking, represents the most recent attempt to convert fragmented bilateral exchange relationships into a single national governance structure (Assistant Secretary for Technology Policy/Office of the National Coordinator for Health Information, 2024b). The conceptual logic connecting Health Information Organisation (HIO) participation, national- and vendor-network participation, and TEFCA can be summarised as a layered progression: HIO participation supports localised information exchange, national and vendor networks extend connectivity across organisational and geographic boundaries, and TEFCA participation represents engagement with a nationwide governance and exchange structure that sits atop these networks rather than substituting for them.

Successive ONC data briefs document that this progression has not been uniform across the hospital sector. Small, rural, and independent hospitals have consistently lagged in interoperable exchange relative to larger, urban, system-affiliated hospitals (Office of the National Coordinator for Health Information, 2018, 2021, 2023). Everson et al. (2023) extend this finding by showing that hospitals serving socially and economically marginalised populations are also less likely to engage in interoperable exchange, and that Critical Access Hospital status is independently associated with lower interoperability engagement even after accounting for social deprivation. What remains underdeveloped in this literature is an explicit empirical link between network-level participation and TEFCA participation specifically, as opposed to interoperability engagement broadly defined. Much of the existing evidence describes interoperability as a general capacity rather than testing whether the specific network relationships a hospital holds are associated with its regulatory participation in the newest national governance layer.

2.4 Hospital Digital Capability and Organisational Readiness

A separate body of work addresses hospital-level digital maturity and organisational readiness more directly, though largely through qualitative or single-country lenses. Burmann et al. (2022) surveyed hospital managing directors in Germany. They found that self-assessed digital maturity varied systematically by hospital size and ownership, a pattern consistent with resource-based explanations of technology adoption. Within the United States specifically, a decade-long assessment of electronic health record adoption found that despite near-universal basic adoption by 2019, comprehensive functionality remained persistently lower among smaller, rural, and independent hospitals relative to larger, system-affiliated facilities (Jiang et al., 2023). System affiliation itself has been shown to matter most for the smallest hospitals: Li et al. (2008) found that small hospitals owned by a multihospital system achieved significantly higher electronic-record adoption levels than comparable independent hospitals, while no such advantage was detectable among medium and large hospitals, suggesting that organisational affiliation substitutes for scale specifically where internal resources are most constrained. In the United States hospital context, financial distress research demonstrates that rural and Critical Access Hospitals

operate under persistent capital constraints that limit discretionary investment, including investment in interoperability infrastructure (Holmes et al., 2017). Read alongside Everson et al. (2023), this suggests that organisational readiness for digital-governance participation is not evenly distributed but is instead patterned by the same structural characteristics, ownership, hospital type, system affiliation, and rurality, which determine broader financial and operational capacity.

The methodological consequence is that studies treating digital capability as a single binary indicator (adopted or not adopted) risk understating the graduated nature of hospital digital-governance capacity. Few studies attempt to combine multiple network-participation indicators into a composite organisational capability measure and subsequently assess its structural robustness against alternative constructions, a gap that motivates the Digital Governance Capability Index (DGCI) developed in the present study.

2.5 Hospital Management and Leadership Challenges

Leadership scholarship in digital health has grown substantially but remains predominantly conceptual and qualitative. Laukka et al. (2022), building on an earlier registered protocol (Laukka et al., 2021), conducted a concept analysis identifying informatics competence, understanding of system complexity, and visionary strategic thinking as recurring attributes of effective leadership in digital health services. Kiljunen et al. (2022) extend this line of inquiry to remote leadership specifically, while Tanniru et al. (2018) propose a four-platform model of digital leadership, comprising innovation, agile delivery, organisational learning, and adoption, illustrated through a single community hospital case study.

This literature is analytically rich but empirically thin at the population level. Leadership attributes and platforms are typically derived from case studies or concept-analysis methods rather than tested against observable, hospital-level regulatory or utilisation outcomes across a national sample. Consequently, while the literature offers a persuasive account of what effective digital leadership might look like, it offers comparatively little evidence on whether hospitals exhibiting stronger measurable digital-governance capability actually experience different regulatory or utilisation outcomes, a gap that the present study's hospital-level and state-level empirical models are designed to address.

2.6 Telemedicine Utilisation and Inequality

Disparities in telemedicine utilisation have been documented with considerable consistency across data sources and time periods. Chen et al. (2021) found that rural and urban hospitals differed systematically in both telehealth adoption and the barriers they reported to sustaining it. Beneficiary-level analyses corroborate a persistent rural-urban utilisation gap even after temporary interstate licensure waivers expanded cross-border telehealth delivery (Andino et al., 2022), and Johannes et al. (2023) report that this gap narrowed but did not close as the acute phase of the pandemic receded.

Where this literature is comparatively underdeveloped is in linking patient-level or beneficiary-level disparities back to the organisational and regulatory characteristics of the hospitals and networks serving those populations. Disparities are typically explained through demand-side factors, broadband access, digital literacy, insurance status, with supply-side explanations, whether the hospitals and exchange networks serving a given population possess adequate digital-governance capability, addressed less directly. The state-level ecological analysis in the present study responds to this gap by testing whether aggregate hospital digital-governance capability is associated with aggregate telehealth utilisation at the population level, while explicitly avoiding the inferential overreach of attributing individual-level disparities to a state-level association.

2.7 Theoretical Foundation

Two complementary theoretical perspectives underpin the conceptual framework developed here. Dynam-

ic Capabilities Theory holds that organisations sustain competitive and operational relevance through the interdependent processes of sensing emerging opportunities and threats, seizing them through resource commitment, and reconfiguring internal assets and routines as the environment shifts (Teece, 2007; Teece et al., 1997). Applied to hospital digital governance, sensing corresponds to a hospital's recognition of the regulatory and interoperability environment as consequential, seizing corresponds to the decision to invest in HIO, national-network, or vendor-network participation, and reconfiguring corresponds to the ongoing adjustment required to remain compliant as frameworks such as TEFCA evolve.

Institutional Theory offers a complementary account of why hospitals pursue these investments even absent a clear efficiency case. DiMaggio and Powell (1983), extending (Meyer & Rowan, 1977)'s foundational argument that formal organisational structures often serve legitimacy functions independent of technical efficiency, identify coercive, mimetic, and normative mechanisms through which organisations in a shared field converge toward similar practices. Applied specifically to health information technology, Sherer et al. (2016) and Chu et al. (2021) find empirical support for all three mechanisms in electronic health record and health information exchange adoption decisions, while Currie (2012)'s longitudinal study of a large national electronic-record programme illustrates that institutional isomorphism can coexist with substantial implementation resistance and delay, cautioning against treating regulatory convergence as a smooth or inevitable process.

Read together, these two theories are complementary rather than competing. Institutional theory explains why regulatory participation, including TEFCA, generates pressure toward convergence across the hospital field, while dynamic capabilities theory explains why hospitals differ in their capacity to respond to that pressure despite facing broadly similar institutional expectations. The observable network-participation indicators capture dimensions of organisational capacity that dynamic capabilities theory would predict to be unevenly distributed, while their associations with TEFCA participation provide an empirical representation of differential organisational responses within a common institutional environment. The broader DGCI subsequently summarises these observable dimensions of digital-governance participation for descriptive and system-level analysis.

2.8 Proposed Conceptual Framework

The conceptual framework positions participation in HIOs, national networks, and vendor-mediated exchange networks as observable dimensions of hospital digital-exchange capability that may support regulatory adaptation, operationalised in the hospital-level analysis as current TEFCA participation. These exchange indicators, together with TEFCA participation, are subsequently combined to form the broader DGCI for descriptive, structural-robustness, and state-level ecological analyses. Hospital organisational characteristics, including ownership and hospital type, are expected to independently shape regulatory participation, consistent with the readiness literature reviewed in Section 2.4. At the system level, the framework extends to a state-level relationship between aggregated hospital DGCI and aggregate Medicare telehealth utilisation, reflecting the utilisation-inequality concerns raised in Section 2.6. Leadership and management, while not directly measured in the hospital-level or state-level data, surround this framework as the organisational mechanism through which sensing, seizing, and reconfiguring are enacted and through which institutional pressures are interpreted and acted upon within individual hospitals.

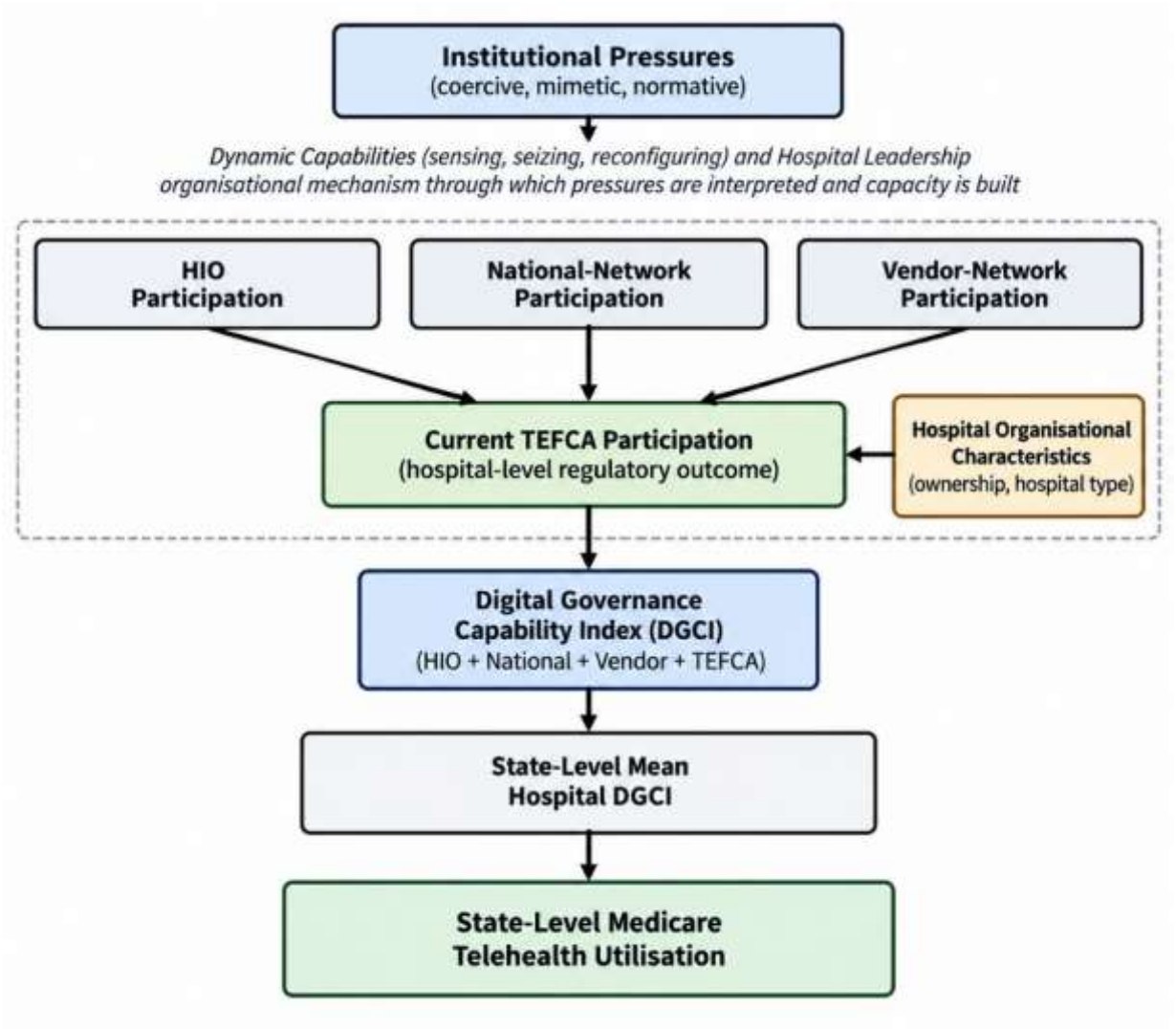


Figure 1. Conceptual framework linking institutional pressures, digital-exchange capability, TEFCA participation, the DGCI, and state-level telehealth utilisation, with dynamic capabilities and leadership as the surrounding organisational mechanism

2.9 Research Gap and Hypothesis Development

The literature reviewed above converges on four specific gaps. First, network-participation indicators and TEFCA participation remain insufficiently examined as a direct, adjusted association within a single hospital-level analysis, despite a substantial descriptive literature on interoperability disparities. Second, organisational readiness factors, particularly ownership and Critical Access Hospital status, are well documented as correlates of general interoperability but have received limited empirical examination specifically in relation to current TEFCA participation. Third, the relationship between aggregate hospital digital-governance capability and telehealth utilisation remains underexamined at the state level, despite parallel literatures on hospital capability and on utilisation disparities that each imply such a relationship should exist. Fourth, the literature provides limited evidence on transparent composite measures that integrate multiple observable dimensions of hospital digital-governance participation and evaluate their structural robustness using both data-driven and component-sensitivity approaches.

These gaps motivate four hypotheses. H1 proposes that hospital participation in digital exchange networks, HIO, national-network, and vendor-network participation, is positively associated with TEFCA participation, directly testing the interoperability-to-regulation pathway identified in Section 2.3. H2 proposes that hospital organisational characteristics are significantly associated with TEFCA participation after accounting for digital-network capability, testing the readiness arguments developed in Section 2.4. H3 proposes that greater state-level hospital digital-governance capability is positively associated with Medicare telehealth utilisation, addressing the supply-side gap identified in Section 2.6. H4 proposes that the DGCI will demonstrate structural robustness across alternative construction and component-sensitivity analyses, while the associations between digital-network participation and TEFCA participation will remain substantively consistent across extended model specifications, directly responding to the composite-measure gap identified above. Leadership is deliberately not framed as a directly measured predictor of TEFCA adoption in these hypotheses, since, consistent with the leadership literature reviewed in Section 2.5, leadership was not observed in the underlying data and should instead be treated as the organisational mechanism that explains, rather than as a variable that statistically predicts, the associations tested.

3. Materials and Methods

3.1 Study Design

This study employed a multi-source observational design that combined hospital-level cross-sectional analysis, longitudinal descriptive analysis of telehealth utilisation, and state-level ecological analysis. The cross-sectional component examined associations between hospital digital-network participation, organisational characteristics, and engagement with the Trusted Exchange Framework and Common Agreement (TEFCA). The longitudinal component described national and subgroup trends in Medicare telehealth utilisation using source data covering 2020 to 2024, with the latest analytically complete year varying by stratification. The ecological component examined the association between aggregated state-level hospital digital-governance capability and state-level telehealth utilisation, using 2023 as the latest year with complete comparable state-level observations. This layered design allowed digital-governance capability to be examined at the institutional level, where regulatory participation is decided, and at the system level, where utilisation outcomes are observed.

3.2 Data Sources

Four publicly available administrative datasets were integrated for this analysis (Table 1). Hospital participation in national and vendor-mediated health information exchange networks, in Health Information Organisations (HIOs), and in TEFCA was obtained from the Office of the National Coordinator for Health Information Technology (ONC/ASTP) hospital network and TEFCA participation dataset. Hospital-level compliance with Promoting Interoperability requirements, together with certified health information technology product identifiers, was obtained from the ONC Promoting Interoperability performance dataset. Because this source reports data at the certified-product level, records were aggregated to the hospital-year level before analysis. Promoting Interoperability information was retained as a supplementary interoperability and compliance measure and for linkage-quality assessment, rather than as a primary predictor in the main TEFCA regression, which relies on the network-participation and organisational variables described in Section 3.4. General organisational characteristics, including ownership type, hospital type, emergency service provision, and CMS overall quality rating, were obtained from the CMS Hospital General Information dataset. Medicare telehealth utilisation, disaggregated by

beneficiary sex, age, race and ethnicity, Medicare or Medicaid enrolment status, and rural or urban residence, was obtained from the CMS Medicare Telehealth Trends report.

Table 1. Data sources, variables, and analytical roles

Data source	Unit of analysis	Period	Key variables	Analytical role
ONC/ASTP Hospital Network and TEFCA Participation	Hospital (CCN)	Current status	HIO participation; national-network participation; vendor-network participation; current TEFCA participation; planned TEFCA participation	Digital-network predictors; primary regulatory outcome (TEFCA)
ONC Promoting Interoperability Performance	Certified product (aggregated to hospital-year)	2023 reporting year	Meets Promoting Interoperability criteria; certified health IT developer and product identifiers	Supplementary interoperability-compliance indicator
CMS Hospital General Information	Hospital (CCN)	Current status	Ownership type; hospital type; emergency services; overall hospital quality rating; state	Organisational controls
CMS Medicare Telehealth Trends	State-quarter, national-quarter	2020 to 2024 (source coverage); 2023 latest complete state-level year	Telehealth-eligible beneficiaries; telehealth beneficiaries; beneficiary sex, age, race/ethnicity, enrolment status, rurality	Telemedicine utilisation outcome

3.3 Data Integration and Sample Construction

Records across the four sources were linked using the six-digit CMS Certification Number (CCN) as a common identifier. Certification numbers were standardised by removing non-numeric characters and left-padding to six digits before matching. The ONC network and TEFCA dataset formed the analytic base, comprising 3,380 hospitals with a valid, unique CCN. Linkage against the Promoting Interoperability dataset was achieved for 97.9 percent of these hospitals, linkage against the CMS Hospital General Information dataset was achieved for 97.3 percent, and three-way linkage across all sources was achieved for 97.2 percent. This high linkage rate indicates minimal sample attrition attributable to record linkage and supports hospital-level modelling with limited loss of organisational or interoperability information. Full linkage-quality statistics are reported in the Results section.

3.4 Variables

Primary regulatory outcome

The primary outcome for the hospital-level analysis was current participation in TEFCA, coded as a binary indicator.

TEFCA_i = 1 if participating; 0 otherwise

Hospitals recorded as planning future TEFCA participation, rather than currently participating, were coded as non-participating for this outcome. This distinction reflects the study's focus on realised rather than intended regulatory engagement and was applied consistently in the construction of the Digital Governance Capability Index described in Section 3.5.

Digital capability predictors

Three binary predictors captured hospital participation in digital exchange infrastructure: participation in a Health Information Organisation, participation in a national health information exchange network, and participation in a vendor-mediated exchange network.

Organisational controls

Hospital ownership type, categorised as government, proprietary, or voluntary non-profit with further subcategories retained where cell sizes permitted stable estimation, was included as a control, together with hospital type, which distinguished Critical Access Hospitals from other facility types. Provision of emergency services and CMS overall hospital quality rating were included as additional organisational controls. State of location was retained for the sensitivity specification incorporating state fixed effects.

Telemedicine outcome

Medicare telehealth utilisation was defined at the population level as the ratio of telehealth beneficiaries to telehealth-eligible beneficiaries within a given quarter and geography.

Telehealth Rate = Telehealth Beneficiaries / Telehealth-Eligible Beneficiaries

This measure was examined nationally over time and, for the ecological analysis, aggregated to the state-year level.

3.5 Digital Governance Capability Index

To summarise each hospital's overall position within the digital-governance environment, a Digital Governance Capability Index (DGCI) was constructed from the four available governance indicators: HIO participation, national-network participation, vendor-network participation, and current TEFCA participation. The index was calculated as an unweighted average of the four binary indicators, rescaled to a 0 to 100 range.

DGCI_i = [(HIO_i + National_i + Vendor_i + TEFCA_i) / 4] × 100

Scores range from 0, indicating no current participation in any governance domain, to 100, indicating participation across all four domains. Equal weighting was adopted for transparency and ease of interpretation, given the absence of an established, externally validated weighting scheme for these indicators. The robustness of this additive construction was subsequently examined using principal component analysis and leave-one-component-out sensitivity analysis, described in Section 3.7.

Because current TEFCA participation formed one component of the DGCI, the composite index was not entered as a predictor in hospital-level models where TEFCA participation was the dependent variable. Instead, the three underlying network-participation indicators were modelled separately, as described in Section 3.6.3. DGCI was used primarily for descriptive, structural-robustness, and state-level ecological analyses, avoiding circularity between the outcome and the composite index.

3.6 Statistical Analysis

3.6.1 Descriptive analysis

Descriptive statistics summarised hospital organisational characteristics, the prevalence of each digital-network indicator, and the distribution of DGCI scores across the analytic sample. National and subgroup

trends in Medicare telehealth utilisation were summarised across the available 2020–2024 source period, with the latest analytically complete year varying by stratification. State-level ecological analysis used 2023, the latest year with complete comparable observations for the required measure.

3.6.2 Assessment of DGCI Structural Robustness

The structural robustness of the additive DGCI was assessed against a data-driven alternative constructed through principal component analysis (PCA) of the standardised governance indicators. Agreement between the additive index and the first principal component was quantified using Pearson and Spearman correlation coefficients. A leave-one-component-out sensitivity analysis was additionally conducted, in which each governance indicator was iteratively removed from the additive calculation and the resulting reduced index was correlated with the full four-indicator index, to assess the influence of any single indicator on the overall score.

3.6.3 Hospital-level logistic regression

The association between digital-network participation and TEFCA participation was estimated using multivariable logistic regression.

$$\text{logit}[P(TEFCA_i=1)] = \beta0 + \beta1 \cdot HIO_i + \beta2 \cdot National_i + \beta3 \cdot Vendor_i + \gamma \cdot Z_i$$

where Z_i represents the vector of hospital organisational controls. Four nested specifications were estimated. Model 1 included only the three network-participation indicators. Model 2 added hospital ownership and hospital type. Model 2 was designated as the primary adjusted inferential specification because it incorporated the core organisational characteristics most directly relevant to hospital management while preserving a parsimonious model. Models 3 and 4 were treated as extended sensitivity specifications incorporating additional organisational and geographic adjustment. Model 3 extended Model 2 with emergency service provision and CMS overall hospital rating. Model 4 further incorporated state fixed effects, retained only where the resulting design matrix remained full rank and estimable. Ownership and hospital-type categories containing fewer than 50 observations were excluded from the conventional inferential models rather than pooled into a heterogeneous residual category, in order to avoid artificial heterogeneity and estimation instability. Odds ratios, 95 percent confidence intervals, and p-values were reported for all fitted specifications. Where conventional maximum-likelihood estimation proved unstable, an L2-regularised logistic specification was fitted as a sensitivity analysis, with stability assessed by coefficient direction and relative ordering across multiple penalty strengths.

3.6.4 State-level ecological analysis

Hospital-level DGCI scores were aggregated to the state-year level and merged with the corresponding Medicare telehealth utilisation rate. The primary ecological analysis used 2023, the latest year with complete comparable state-level observations for the required telehealth measure. This cross-sectional association was estimated using ordinary least squares regression with heteroscedasticity-consistent (HC3) standard errors.

$$\text{Telehealth Rate} = \beta0 + \beta1 \cdot (\text{State DGCI}) + \varepsilon$$

This analysis is explicitly ecological in nature. Associations identified at the state level describe the relationship between aggregated hospital digital-governance capability and aggregated telehealth utilisation and do not support inference regarding individual hospitals or individual patients.

3.6.5 Machine-learning robustness analysis

As a supplementary, exploratory robustness check, a Random Forest classifier was trained to predict TEFCA participation from the three network-participation indicators, using a stratified 75/25 train-test split and class-balanced weighting. Model discrimination was assessed using the area under the receiver

operating characteristic curve, together with accuracy, precision, recall, and F1 score on the held-out test set. Feature importance was further examined using SHapley Additive exPlanations (SHAP) to characterise the relative contribution of each network indicator to predicted TEFCA participation. This analysis was treated as corroborating evidence for the regression-based findings rather than as a standalone predictive or clinically deployable model.

3.7 Sensitivity, Robustness and Model Diagnostics

Several diagnostic procedures assessed the stability and validity of the primary findings. Principal component analysis and leave-one-component-out correlation, described in Section 3.6.2, assessed the robustness of the DGCI. For the primary adjusted TEFCA model, variance inflation factors were calculated for all covariates to assess multicollinearity, and the rank of the design matrix was verified to confirm identifiability of all estimated parameters. L2-regularised logistic regression was specified as an additional sensitivity procedure for assessing coefficient stability where conventional maximum-likelihood estimation showed evidence of numerical instability. Data-quality checks, including minimum thresholds for dataset completeness and linkage rates, were applied before analysis to verify the integrity and adequacy of the merged analytic dataset.

All analyses were conducted in a Python 3 environment using pandas and NumPy for data management, statsmodels for logistic and ordinary least squares regression, scikit-learn for principal component analysis and the Random Forest classifier, and SHAP for feature-importance explanation. A fixed random seed (42) was applied to all stochastic procedures, including the train-test split and the Random Forest estimator, to support reproducibility.

3.8 Ethical Considerations and Data Availability

This study relied exclusively on publicly available, de-identified, aggregate administrative data published by the Office of the National Coordinator for Health Information Technology and the Centers for Medicare and Medicaid Services. No individual patients or clinicians were recruited, contacted, or directly observed, and no protected health information was accessed at any stage of data collection or analysis. As the study involved secondary analysis of publicly released, non-interventional, hospital- and population-level datasets, it did not constitute human subjects research requiring individual informed consent. Formal institutional review board exemption was not sought or claimed because the analysis was restricted to publicly released, de-identified administrative data; applicable institutional and journal policies were followed. All source datasets are publicly accessible through the ONC/ASTP and CMS data portals cited in Table 1, and the compiled analytic files and code are available from the corresponding author upon reasonable request.

4. Results

4.1 Sample Characteristics and Data Linkage

The analytic base comprised 3,380 hospitals with a valid, unique CMS Certification Number (CCN) in the ONC/ASTP hospital network and TEFCA participation dataset. Linkage against the Promoting Interoperability dataset, which contained 4,654 unique hospital-level CCNs, and against the CMS Hospital General Information dataset, which contained 5,411 unique CCNs, achieved rates of 97.9 percent and 97.3 percent, respectively. Three-way linkage across all three sources was achieved for 97.2 percent of the analytic base (Table 2). This linkage performance indicates that the merged analytic file retained the great majority of hospitals from the network dataset with minimal loss attributable to record matching, supporting the organisational and interoperability modelling reported in Sections 4.4 and 4.7.

Table 2. Hospital sample and linkage quality

Metric	Value
Network/TEFCA hospitals (analytic base)	3,380
CMS Hospital General Information, unique CCNs	5,411
Promoting Interoperability, unique CCNs	4,654
Network to Promoting Interoperability linkage	97.9%
Network to CMS General Information linkage	97.3%
Three-way linkage (Network, PI, CMS)	97.2%

4.2 Distribution of Digital-Governance Capabilities

Among the 3,380 hospitals in the analytic sample, participation in a Health Information Organisation was the most prevalent governance indicator, reported by 81.6 percent of hospitals, followed by participation in a national health information exchange network (72.3 percent) and participation in a vendor-mediated exchange network (54.4 percent). Current TEFCA participation was reported by 34.4 percent of hospitals, with an additional 38.6 percent reporting planned, but not yet realised, participation.

The composite Digital Governance Capability Index, constructed from these four indicators, had a mean of 60.7 (SD = 28.2, median = 75.0, range 0 to 100) across the full sample (Figure 2). The distribution was left-skewed, with a substantial cluster of hospitals scoring at or above the median and a smaller group of hospitals reporting no current participation in any of the four governance domains.

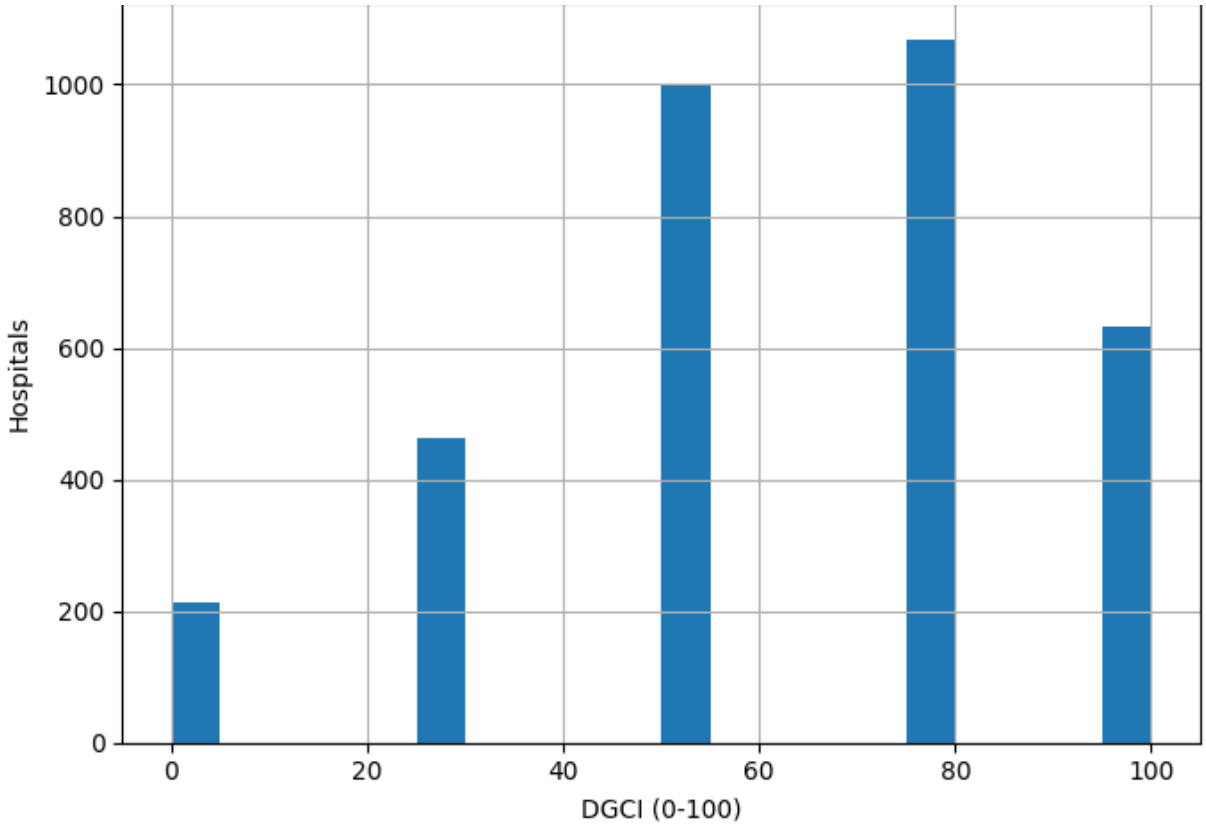


Figure 2. Distribution of the Digital Governance Capability Index (DGCI) across 3,380 hospitals

4.3 Structural Robustness of the Digital Governance Capability Index

The additive DGCI demonstrated strong agreement with a data-driven index constructed from the first principal component of the four governance indicators. Pearson and Spearman correlations between the additive and PCA-derived indices were .998 and .976, respectively. The first principal component accounted for 38.8 percent of total variance across the four indicators, with the remaining three components accounting for 22.4 percent, 20.7 percent, and 18.1 percent, respectively (Table 3). All four indicators loaded positively on the first component, supporting the presence of a shared dimension across the governance indicators.

Leave-one-component-out sensitivity analysis, in which each governance indicator was iteratively removed from the additive calculation, produced Spearman correlations with the full four-indicator index ranging from .888, when vendor-network participation was omitted, to .948, when HIO participation was omitted. These results indicate that no single indicator disproportionately determined the additive DGCI score, supporting the robustness of the equal-weighting approach adopted in the Methods section.

Table 3. DGCI construction, PCA comparison, and sensitivity analysis

Statistic	Value
DGCI mean (SD), n = 3,380	60.7 (28.2)
DGCI median (range)	75.0 (0 to 100)
First principal component, variance explained	38.8%
Pearson r, additive DGCI vs. PCA index	.998
Spearman rho, additive DGCI vs. PCA index	.976
Leave-one-component-out rho, range	.888 to .948

4.4 Determinants of TEFCA Participation

Table 4 reports odds ratios from the nested logistic regression models predicting current TEFCA participation. In the network-only model (M1, n = 3,380), all three digital-network indicators were independently and positively associated with TEFCA participation, with national-network participation showing the largest association in M1 (OR = 3.29, 95% CI 2.70 to 4.01, $p < .001$), followed by vendor-network participation (OR = 1.91, 95% CI 1.63 to 2.22, $p < .001$) and HIO participation (OR = 1.31, 95% CI 1.06 to 1.62, $p = .012$).

The primary adjusted model (M2, n = 3,185), incorporating hospital ownership and hospital type, produced consistent and, for HIO and vendor-network participation, somewhat stronger associations. National-network participation showed the largest adjusted association with TEFCA participation (OR = 3.25, 95% CI 2.64 to 4.00, $p < .001$), followed by vendor-network participation (OR = 2.25, 95% CI 1.90 to 2.67, $p < .001$) and HIO participation (OR = 1.49, 95% CI 1.19 to 1.87, $p < .001$). Among organisational characteristics, proprietary ownership was associated with substantially higher odds of TEFCA participation relative to the reference ownership category (OR = 2.50, 95% CI 1.79 to 3.49, $p < .001$), while Critical Access Hospital status was associated with lower odds of participation (OR = 0.71, 95% CI 0.59 to 0.85, $p < .001$). Government, church-affiliated, and other voluntary non-profit ownership categories did not differ significantly from the reference category (all $p > .39$). Model 2 had a pseudo-R2 of .094, compared with .069 for Model 1.

Sensitivity specifications extending the primary model produced substantively consistent results. Model 3 (n = 2,414), which added emergency service provision and CMS overall hospital rating, retained significant associations for national-network (OR = 3.31), vendor-network (OR = 2.27), and HIO

participation (OR = 1.30, p = .041); overall hospital rating was weakly and inversely associated with TEFCA participation (OR = 0.90, 95% CI 0.82 to 0.98, p = .011), while emergency service provision was not a significant predictor. Model 4 (n = 2,267), incorporating state fixed effects, produced substantively similar network-participation associations, with national-network participation remaining the largest association across all specifications (OR = 4.09, 95% CI 3.13 to 5.35, p < .001). Model 4's solver did not satisfy the default maximum-likelihood convergence tolerance, associated principally with a sparse North Dakota outcome cell; because Model 4 was specified only as a sensitivity analysis rather than the primary inferential model, its estimates, except for the unstable North Dakota coefficient, are interpreted cautiously. As a robustness check, M4 was re-estimated using L2-regularised logistic regression on the identical complete-case sample (N = 2,267). The regularised estimates preserved the positive direction and relative ordering of the three network associations (national network greater than vendor network greater than HIO), and this ordering remained stable across a range of penalty strengths. Full results are provided in Supplementary Materials. Variance inflation factors for all covariates in the primary model remained below 3.0, indicating no material multicollinearity.

Table 4. Associations between hospital digital-network participation and current TEFCA participation: logistic regression models

Term	M1: OR (95% CI)	M2: OR (95% CI)
HIO participation	1.31 (1.06, 1.62)*	1.49 (1.19, 1.87)***
National-network participation	3.29 (2.70, 4.01)***	3.25 (2.64, 4.00)***
Vendor-network participation	1.91 (1.63, 2.22)***	2.25 (1.90, 2.67)***
Proprietary ownership (ref: government, federal)	not modelled	2.50 (1.79, 3.49)***
Critical Access Hospital status	not modelled	0.71 (0.59, 0.85)***
N	3,380	3,185
Pseudo R2	.069	.094

Note. M1 includes the three network-participation indicators only. M2, the primary adjusted specification, additionally controls for hospital ownership (reference category: government, federal) and hospital type (reference category: all hospital types other than Critical Access Hospitals). Extended sensitivity specifications (M3, M4) are summarised in the text and reported in full in Supplementary Materials. * p < .05; ** p < .01; *** p < .001.

4.5 Medicare Telehealth Utilisation Trends

National Medicare telehealth utilisation rose sharply from 6.9 percent of telehealth-eligible beneficiaries in the first quarter of 2020 to a peak of 46.7 percent in the second quarter of 2020, coinciding with the onset of the COVID-19 pandemic (Figure 3). Utilisation declined steadily thereafter, falling to approximately 15.8 percent by the fourth quarter of 2021 and continuing to decline through 2022, reaching approximately 14.8 percent by year end. From 2023 onward, utilisation fluctuated within a narrower range of approximately 12.6 percent to 14.8 percent through the third quarter of 2024, the most recent period covered by the source data.

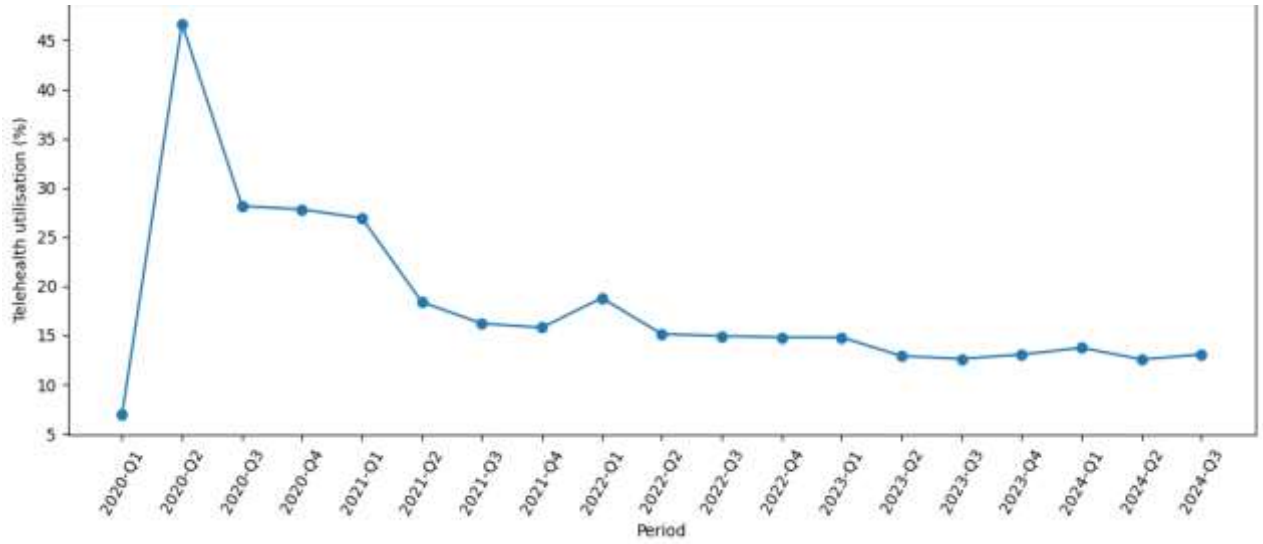


Figure 3. National Medicare telehealth utilisation by quarter, 2020 to 2024

4.6 Rural-Urban Differences in Telehealth Utilisation

Rural and urban Medicare beneficiaries exhibited broadly similar utilisation patterns during the initial pandemic surge, with urban utilisation peaking somewhat higher than rural utilisation in the second quarter of 2020, at approximately 49 percent compared with 38 percent. Following the initial decline, urban utilisation consistently exceeded rural utilisation from 2021 onward (Figure 4). In the most recent quarter in the series, the third quarter of 2024, urban utilisation remained higher than rural utilisation (approximately 14.1 percent versus 9.6 percent), indicating a persistent, if narrowed, and geographic difference in sustained telehealth utilisation.

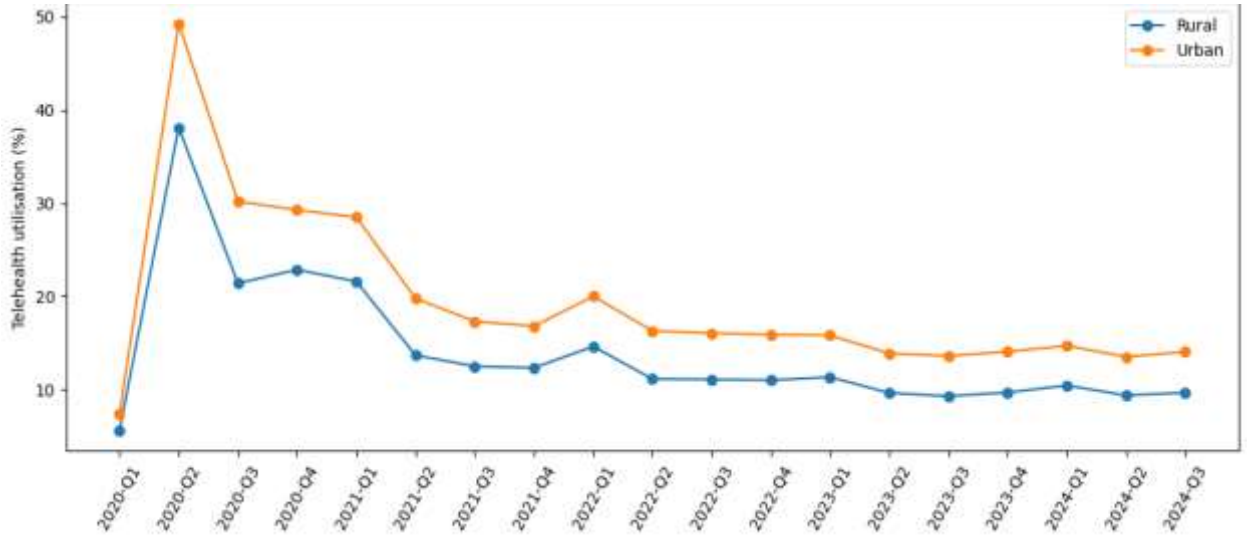


Figure 4. Rural versus urban Medicare telehealth utilisation by quarter, 2020 to 2024

4.7 Digital Governance and Telehealth Utilisation

At the state level, mean hospital DGCI was positively associated with Medicare telehealth utilisation. Using 2023 as the latest year with complete comparable state-level observations, the correlation between state-level mean DGCI and state-level telehealth utilisation was .424 (n = 50 states). Ordinary least squares

regression with heteroscedasticity-consistent standard errors confirmed a statistically significant positive association (b = 0.0032, SE = .001, p = .001) (Figure 5). The model yielded R2 = .179, indicating that approximately 17.9 percent of the cross-state variation in telehealth utilisation was statistically associated with variation captured by state mean DGCI in this bivariate model (F(1,48) = 11.63, p = .001). In practical terms, a 10-point higher mean state DGCI was associated with approximately 3.2 percentage points higher Medicare telehealth utilisation. Consistent with the ecological nature of this analysis, this association describes a state-level pattern and does not support inference regarding individual hospitals or individual patients.

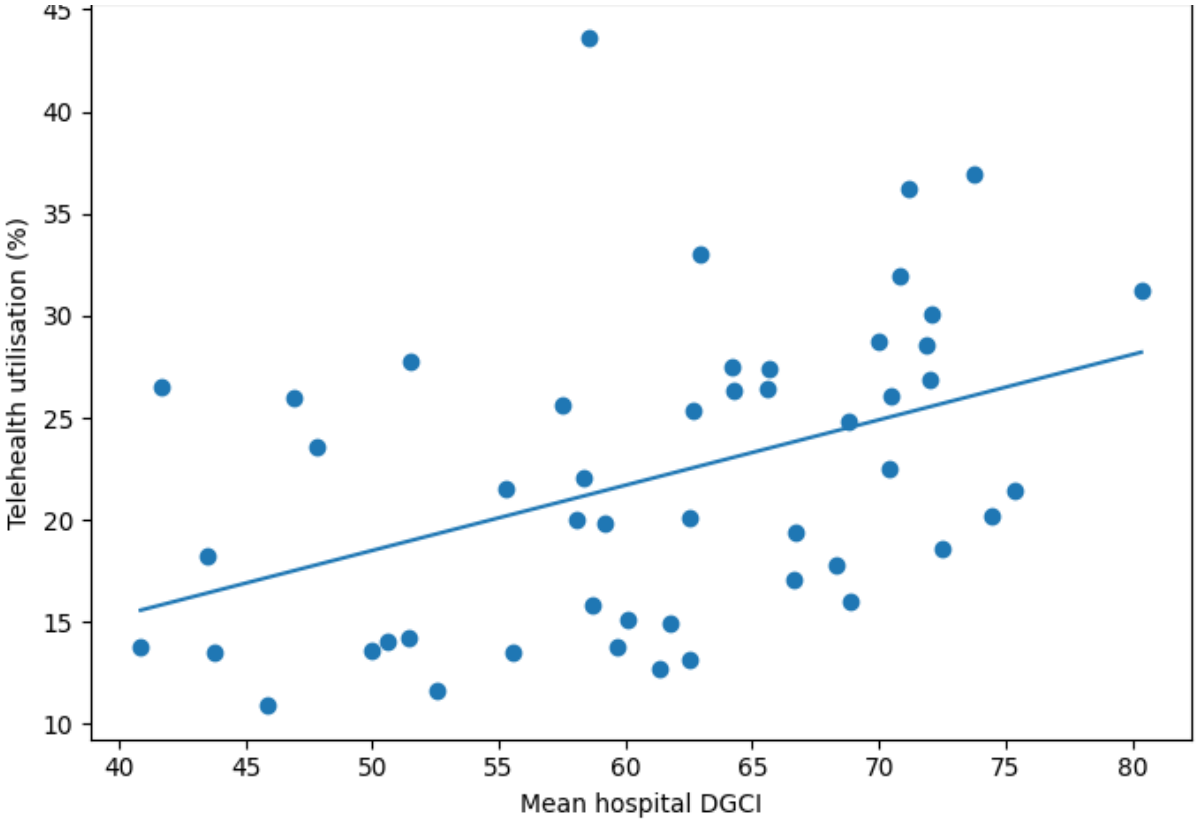


Figure 5. State-level mean hospital DGCI and Medicare telehealth utilisation, 2023

4.8 Exploratory Machine-Learning and Robustness Findings

A Random Forest classifier trained on the three network-participation indicators achieved moderate discrimination in predicting TEFCA participation on the held-out test set (AUC = .676, accuracy = .651, precision = .495, recall = .622, F1 = .551). Feature-importance analysis indicated that national-network participation contributed the largest share of predictive importance (61.9 percent), followed by vendor-network participation (28.1 percent) and HIO participation (9.9 percent). The ranking of predictor importance, national network, vendor network, then HIO, was consistent with the ordering of association magnitudes observed in the logistic regression models reported in Section 4.4. Consistent with its exploratory purpose, this analysis is presented as a robustness check rather than as a clinically deployable prediction model.

4.9 Summary of Hypothesis Testing

H1 was supported: HIO, national-network, and vendor-network participation were each positively and

independently associated with current TEFCA participation in the primary adjusted model. H2 was partially supported: selected hospital organisational characteristics were associated with TEFCA participation, particularly proprietary ownership and Critical Access Hospital status, while other ownership categories and emergency service provision were not significant. H3 was supported at the ecological level: higher state mean DGCI was positively associated with Medicare telehealth utilisation. H4 was supported: the DGCI demonstrated strong structural robustness across PCA and leave-one-component-out analyses, while the principal network-participation associations remained substantively consistent across extended regression specifications.

5. Discussion

5.1 Principal Findings

This study set out to examine how hospital digital-governance capability relates to regulatory participation and telemedicine utilisation, and to situate the resulting patterns within a dynamic-capabilities and institutional-theory framework. Five findings anchor the discussion that follows. First, national-network participation showed the strongest and most consistent association with current TEFCA participation across every model specification, followed by vendor-network and HIO participation. Second, hospital organisational characteristics mattered selectively rather than uniformly: proprietary ownership was associated with substantially higher odds of TEFCA participation, and Critical Access Hospital status with lower odds, while several other ownership categories showed no significant association. Third, the DGCI demonstrated strong structural robustness across principal component analysis and leave-one-component-out sensitivity checks. Fourth, national Medicare telehealth utilisation settled into a materially higher and comparatively stable plateau after 2022, well below the pandemic peak but well above pre-pandemic levels. Fifth, state-level hospital digital-governance capability was positively associated with state-level Medicare telehealth utilisation. Separately, the supplementary machine-learning analysis of hospital-level TEFCA participation produced a ranking of network predictors broadly consistent with the logistic-regression results. Read together, these findings support H1, H3, and H4 in full and H2 in part, and they carry implications that extend beyond the immediate hospital-management literature into institutional theory, dynamic-capabilities research, and digital-health policy.

5.2 Digital Infrastructure as Regulatory Capability

The consistent primacy of national-network participation across M1 through M4 offers a substantive, not merely statistical, insight. Section 2.7 argued that dynamic-capabilities theory and institutional theory are complementary rather than competing explanations for hospital digital-governance behaviour: institutional pressure explains why hospitals face broadly similar incentives to pursue interoperability, while dynamic capabilities explain why hospitals differ in their capacity to respond. The substantially larger association observed for national-network participation, relative to HIO participation, across every specification is consistent with a capability-based interpretation of regulatory adaptation. Although this study does not directly measure the sensing, seizing, or reconfiguring processes proposed by dynamic-capabilities theory, national-network participation may reflect a broader organisational capacity to engage with cross-organisational exchange infrastructure than a single local HIO relationship requires. The findings therefore suggest that institutional pressure alone may be insufficient to explain variation in TEFCA participation; hospitals may also differ in the organisational capabilities that enable them to respond to those pressures.

5.3 Hospital Organisational Differences and Leadership Challenges

The organisational findings extend, rather than merely replicate, the readiness literature reviewed in Section 2.4. The elevated odds of TEFCA participation among proprietary hospitals and the reduced odds among Critical Access Hospitals are consistent with resource-based accounts of digital-network adoption, including evidence that multihospital system affiliation disproportionately benefits small hospitals with constrained internal capacity (Li et al., 2008), that comprehensive electronic health record functionality has remained persistently lower among smaller and rural facilities despite near-universal basic adoption (Jiang et al., 2023), and that rural and Critical Access Hospitals operate under financial constraints that limit discretionary technology investment (Holmes et al., 2017). These associations should not, however, be read as evidence that ownership or hospital type directly causes differential regulatory participation; the modest pseudo-R2 values indicate that the fitted models provide only partial statistical characterisation of TEFCA participation, leaving substantial scope for additional organisational, market, and policy factors. For hospital leadership, the practical implication is that closing the participation gap is unlikely to be achieved through compliance-oriented leadership alone. The leadership literature reviewed in Section 2.5 identifies informatics competence, strategic vision, and organisational-learning capacity as recurring attributes of effective digital health leadership (Laukka et al., 2022; Tanniru et al., 2018); these leadership capabilities may be particularly consequential in resource-constrained settings, including Critical Access Hospitals, where the present analysis identified lower TEFCA participation.

5.4 Regulatory Implications of TEFCA Participation

A central policy tension emerges from these results. TEFCA applies broadly similar expectations to hospitals that begin from markedly different starting positions in digital-governance capability. Where institutional theory predicts convergence toward a shared organisational practice under coercive, mimetic, and normative pressure (DiMaggio & Powell, 1983), the organisational disparities documented here, together with the pre-existing interoperability gaps reported by Everson et al. (2023) for Critical Access Hospitals and marginalised-population-serving hospitals, suggest that uniform regulatory expectations may generate unequal organisational burdens rather than uniform organisational responses. (Currie, 2012)'s longitudinal analysis of a large national electronic-record programme offers a relevant caution here: institutional isomorphism and substantial implementation resistance or delay can coexist, and regulatory convergence should not be assumed to proceed smoothly simply because the pressure to conform is broadly shared. Importantly, the positive association between national-network participation and TEFCA participation remained substantively large in the state-fixed-effects sensitivity specification and was preserved under L2-regularised re-estimation, suggesting that the principal hospital-level pattern was not eliminated by adjustment for time-invariant differences across states.

5.5 Telemedicine Sustainability and Digital Governance

The national telehealth trend described in Section 4.5, a sharp pandemic-era peak followed by decline and stabilisation at a materially higher plateau than before 2020, is consistent with a transition from emergency-scale utilisation toward a smaller, more stable component of routine Medicare service delivery, rather than a return to pre-pandemic norms (Bhaskar et al., 2020; Ndwabe et al., 2024). The state-level ecological finding adds a complementary cross-sectional perspective: states with higher mean hospital DGCI in 2023 also exhibited higher Medicare telehealth utilisation, with a 10-point difference in state mean DGCI corresponding to approximately 3.2 percentage points of difference in Medicare telehealth utilisation. This association is consistent with the possibility that hospital digital-governance environments form part of the broader infrastructure supporting sustained telemedicine use, although the cross-sectional

ecological design cannot establish directionality or causation, and the analysis reflects a single year rather than a longitudinal state-level trend. Digital-health regulation and telemedicine utilisation may therefore represent interconnected dimensions of the wider digital-health ecosystem rather than entirely separate policy domains, a connection that the largely separate utilisation and interoperability literatures reviewed in Sections 2.1 and 2.3 have not directly tested.

5.6 Equity and Access Implications

The persistence of a rural-urban telehealth utilisation gap into the most recent quarter of available data, notwithstanding a substantial narrowing from the pandemic-era peak, echoes a consistent finding across the hospital-adoption and beneficiary-utilisation literatures (Andino et al., 2022; Chen et al., 2021; Johannes et al., 2023). Much of this literature attributes rural-urban disparities to demand-side factors such as broadband availability and digital literacy (Zahnd et al., 2022). The present study does not directly test whether lower hospital digital-governance capability explains the rural-urban utilisation gap; no analysis reported here links hospital rurality, DGCI, and telehealth utilisation within a single model. Nevertheless, the combination of lower TEFCA participation among Critical Access Hospitals, persistent rural-urban differences in telehealth utilisation, and the positive state-level DGCI-telehealth association raises a testable supply-side hypothesis: institutional digital capability may contribute, alongside established demand-side barriers, to geographic differences in telehealth utilisation. Digital transformation in hospital care should accordingly be evaluated not only by whether adoption is occurring, but by whether the hospitals best positioned to sustain that adoption are the same ones serving the populations who show the lowest utilisation.

5.7 Theoretical Contribution

This study contributes to institutional and dynamic-capabilities scholarship by applying the two perspectives jointly to empirical patterns in hospital digital-governance and regulatory participation. The finding that network-participation associations with TEFCA persisted, and in the case of national-network participation strengthened, across increasingly adjusted specifications is consistent with a capability-dependent account of institutional isomorphism: regulatory adaptation appears to require not only the incentive to conform that institutional theory identifies, but also organisational capability of the kind dynamic-capabilities theory identifies as unevenly distributed across organisations (Teece, 2007; Teece et al., 1997). This extends prior applications of institutional theory to health information technology adoption, which have generally examined coercive, mimetic, and normative pressures on adoption decisions without directly modelling the organisational capability that may condition whether those pressures translate into regulatory participation (Chu et al., 2021; Sherer et al., 2016). The proposed conceptual framework, in which institutional pressure and organisational capability jointly shape regulatory participation, offers a template for future health-information-technology research that seeks to avoid treating adoption as either a purely rational compliance decision or a purely externally imposed one, while acknowledging that the present study interprets its empirical patterns through these theories rather than directly measuring the pressures or capabilities the theories describe.

5.8 Managerial Implications

For hospital management, four implications follow from these findings. Interoperability capability should be built as organisational infrastructure before compliance is treated as an isolated regulatory function, since the network relationships most strongly associated with TEFCA participation take time to establish and cannot be assembled at the point a compliance deadline arrives. Regulatory strategy and digital-infrastructure strategy should be integrated rather than managed as separate workstreams, given the

consistent association between network participation and regulatory outcomes documented here. Network participation decisions, HIO, national-network, and vendor-network membership, should be evaluated strategically rather than treated as interchangeable, given their differing strength of association with TEFCA participation. Finally, hospital leadership may benefit from monitoring digital-governance readiness through multidimensional indicators rather than relying solely on binary adoption measures; the DGCI developed here illustrates one research-based approach to such measurement, although further external validation would be required before operational use.

5.9 Policy Implications

For policymakers, the organisational disparities documented here reinforce the case for targeted support to Critical Access and other resource-constrained hospitals rather than uniform regulatory timelines alone. Recent federal action on rural hospital sustainability, including the Centers for Medicare & Medicaid Services' Rural Health Transformation Program, a $50 billion initiative explicitly intended to help states modernise rural health facilities and technology, indicates that this need is increasingly recognised at the policy level (Centers for & Medicaid, 2025), though whether such funding specifically targets digital-governance capability, as distinct from broader facility and workforce investment, remains an open question. Interoperability infrastructure investment and TEFCA implementation support should be explicitly linked to measures of hospital digital-governance readiness, so that regulatory expansion does not widen the capability disparities it is intended to close. More broadly, the ecological association between state-level digital-governance capability and telehealth utilisation suggests that state-level policy environments, not only individual hospital decisions, warrant attention as a potential policy context for supporting sustained telemedicine utilisation and reducing geographic differences.

5.10 Limitations

Several limitations qualify these conclusions. The study design is observational and cross-sectional at the hospital level, so none of the reported associations support causal inference. Leadership was not directly measured in the underlying data and is treated throughout as an inferred organisational mechanism rather than a tested variable. The DGCI is constructed from observable network and regulatory-participation indicators and demonstrated strong structural robustness across data-driven and component-sensitivity checks, but this does not constitute full external construct validation against independent measures of digital governance. The state-level ecological analysis is based on 50 observations for a single year and describes a state-level pattern that does not support inference about individual hospitals or patients. The Medicare Telehealth Trends data used in the ecological analysis reflect Medicare Fee-for-Service (FFS) Part B claims and may not generalise to Medicare Advantage enrollees or non-Medicare populations. The hospital-level and population-level data sources cover overlapping but non-identical periods, and possible unmeasured confounding, including market competition, health-system affiliation beyond the categories captured here, and local regulatory context, cannot be ruled out. Finally, the Random Forest and SHAP analysis is exploratory and corroborative rather than a validated predictive tool, and its correspondence with the regression results should be interpreted as convergent evidence rather than independent confirmation.

5.11 Future Research

Several extensions follow directly from these limitations. Longitudinal tracking of hospital-level TEFCA adoption, as the framework matures beyond its early implementation phase, would allow the network-participation associations documented here to be examined as predictors of subsequent regulatory participation rather than concurrent correlates. Direct measurement of executive leadership behaviour,

through survey or interview-based instruments of the kind used in the concept-analysis literature (Laukka et al., 2021), would allow the organisational-mechanism role assigned to leadership in this study to be tested empirically rather than inferred theoretically. Hospital-level telemedicine utilisation data, where available, would allow the ecological state-level association reported here to be re-examined at the level of the organisations actually delivering care. Comparative analysis of regulatory adaptation between rural and urban hospitals, extending the equity findings in Section 5.6, could clarify whether targeted policy interventions narrow or widen existing capability disparities. Finally, as TEFCA implementation continues to roll out unevenly across states and networks, quasi-experimental designs exploiting this variation could offer stronger causal evidence than the observational associations reported in this study.

6. Conclusion

Digital-health regulation and hospital management in the era of telemedicine cannot be separated from the underlying digital-governance capability that hospitals bring to an increasingly interconnected regulatory environment. This study examined how hospital participation in digital exchange networks, organisational characteristics, and aggregate digital-governance capability relate to regulatory participation in the Trusted Exchange Framework and Common Agreement and to Medicare telehealth utilisation, doing so through the complementary lenses of institutional theory and dynamic-capabilities theory.

The findings indicate that participation in broader digital-exchange networks, particularly national-network participation, was consistently associated with higher odds of current TEFCA participation after adjustment for hospital ownership and hospital type, a pattern that persisted across a series of extended and sensitivity specifications. The ordering of these network associations was also broadly consistent with the feature-importance ranking from the supplementary machine-learning analysis. Organisational characteristics mattered selectively rather than uniformly: proprietary ownership was associated with higher regulatory participation, and Critical Access Hospital status with lower participation, while several other ownership categories showed no distinguishable association. The Digital Governance Capability Index constructed from these indicators demonstrated strong structural robustness, and at the state level, higher aggregate hospital digital-governance capability corresponded to higher Medicare telehealth utilisation, an association that remains ecological and cross-sectional in nature.

Read together, these findings are consistent with a view of regulatory adaptation that incorporates both institutional pressure and organisational capability. Institutional theory helps explain why hospitals face a broadly shared incentive to participate in emerging governance structures such as TEFCA; dynamic-capabilities theory helps explain why hospitals differ, often substantially, in their capacity to respond to that incentive. This carries direct implications for hospital leadership. Because leadership was not directly measured in this study, it has been treated throughout as the organisational mechanism through which digital-governance capability is built and through which institutional pressure is interpreted and acted upon, rather than as a variable whose effects can be read from a regression coefficient.

The leadership challenge that emerges from this study is accordingly not a challenge of compliance alone. It is a challenge of building interoperability infrastructure before regulatory deadlines require it, recognising that organisational characteristics such as ownership and Critical Access status shape the starting point from which that infrastructure must be built, and treating regulatory strategy, digital investment, and efforts to reduce disparities in telemedicine utilisation as interdependent responsibilities rather than separate functions. The findings indicate that hospitals with stronger digital-network participation are better positioned within emerging national interoperability structures, while states with

higher aggregate hospital digital-governance capability also exhibit higher Medicare telehealth utilisation. These relationships should not be interpreted causally, but together they underscore the strategic importance of interoperability, organisational readiness, and digital-governance capacity in the evolving telemedicine environment. Digital-health regulation and hospital management are therefore increasingly interconnected dimensions of the same broader organisational challenge.

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Supplementary Materials

Table S1. Model 3 (fully adjusted: network, ownership, hospital type, emergency services, and overall rating), full specification

Term	Coef.	OR	95% CI	p
Intercept	-1.841	0.16	0.09 to 0.30	<.001
Ownership: Government - Local	-0.061	0.94	0.58 to 1.53	0.806

Ownership: Proprietary	0.954	2.60	1.74 to 3.87	<.001
Ownership: Voluntary non-profit - Church	-0.012	0.99	0.63 to 1.55	0.959
Ownership: Voluntary non-profit - Other	-0.221	0.80	0.51 to 1.25	0.333
Ownership: Voluntary non-profit - Private	-0.159	0.85	0.60 to 1.21	0.372
Hospital type: Critical Access Hospitals	-0.103	0.90	0.69 to 1.18	0.453
HIO participation	0.264	1.30	1.01 to 1.68	0.041
National-network participation	1.196	3.31	2.60 to 4.21	<.001
Vendor-network participation	0.818	2.27	1.86 to 2.75	<.001
Emergency services (binary)	0.034	1.03	0.68 to 1.57	0.873
CMS overall hospital rating (numeric)	-0.109	0.90	0.82 to 0.98	0.011

Note. N = 2,414. Pseudo-R2 = .079. Reference categories: government/federal ownership; non-Critical-Access hospital type.

Table S2. Model 4 (Model 3 plus state fixed effects), full specification

Term	Coef.	OR	95% CI	p
Intercept	-2.557	0.08	0.02 to 0.24	<.001
Ownership: Government - Local	0.059	1.06	0.61 to 1.85	0.837
Ownership: Proprietary	1.058	2.88	1.82 to 4.55	<.001
Ownership: Voluntary non-profit - Church	0.104	1.11	0.66 to 1.87	0.697
Ownership: Voluntary non-profit - Other	-0.203	0.82	0.49 to 1.36	0.437
Ownership: Voluntary non-profit - Private	-0.043	0.96	0.64 to 1.44	0.834
Hospital type: Critical Access Hospitals	-0.158	0.85	0.62 to 1.18	0.333
State: AR	0.393	1.48	0.44 to 4.93	0.522
State: AZ	-0.835	0.43	0.11 to 1.78	0.245
State: CA	-0.391	0.68	0.25 to 1.83	0.440
State: CO	1.066	2.90	0.93 to 9.03	0.066
State: FL	1.760	5.81	2.12 to 15.90	<.001
State: GA	1.691	5.43	1.79 to 16.44	0.003
State: IA	0.853	2.35	0.76 to 7.24	0.138
State: IL	0.963	2.62	0.94 to 7.31	0.066
State: IN	0.580	1.79	0.60 to 5.35	0.300
State: KS	1.792	6.00	1.87 to 19.23	0.003
State: KY	-0.512	0.60	0.18 to 1.95	0.395
State: LA	1.499	4.48	1.45 to 13.86	0.009
State: MA	0.941	2.56	0.80 to 8.17	0.112
State: MD	1.687	5.40	1.69 to 17.30	0.004
State: MI	0.944	2.57	0.89 to 7.46	0.082
State: MN	1.364	3.91	1.24 to 12.31	0.020
State: MO	0.554	1.74	0.60 to 5.02	0.306
State: MS	0.483	1.62	0.50 to 5.22	0.418
State: MT	-0.369	0.69	0.14 to 3.41	0.651
State: NC	1.247	3.48	1.22 to 9.97	0.020

State: ND	-22.957	0.00	0.00 to inf	1.000
State: NE	-0.793	0.45	0.09 to 2.16	0.320
State: NJ	0.457	1.58	0.52 to 4.82	0.423
State: NY	0.183	1.20	0.42 to 3.43	0.733
State: OH	0.475	1.61	0.57 to 4.54	0.370
State: OK	-0.240	0.79	0.22 to 2.87	0.717
State: OR	0.309	1.36	0.40 to 4.59	0.618
State: PA	0.406	1.50	0.53 to 4.22	0.442
State: SC	1.115	3.05	0.94 to 9.87	0.063
State: SD	-0.532	0.59	0.10 to 3.55	0.562
State: TN	0.174	1.19	0.40 to 3.56	0.756
State: TX	-0.119	0.89	0.33 to 2.40	0.815
State: UT	-0.149	0.86	0.24 to 3.07	0.819
State: VA	0.973	2.64	0.91 to 7.69	0.074
State: WA	-0.310	0.73	0.23 to 2.38	0.606
State: WI	1.498	4.47	1.53 to 13.06	0.006
State: WV	1.587	4.89	1.41 to 16.93	0.012
HIO participation	0.248	1.28	0.95 to 1.72	0.099
National-network participation	1.410	4.09	3.13 to 5.35	<.001
Vendor-network participation	0.702	2.02	1.61 to 2.52	<.001
Emergency services (binary)	0.035	1.04	0.64 to 1.68	0.887
CMS overall hospital rating (numeric)	-0.132	0.88	0.80 to 0.96	0.007

Note. N = 2,267. Pseudo-R2 = .161. Reference state: Alabama. The North Dakota coefficient reflects a near-empty outcome cell and is not interpreted. Model 4's solver did not satisfy the default maximum-likelihood convergence tolerance; it is reported as a sensitivity specification only, and its network-participation coefficients are corroborated by the L2-regularised analysis in Tables S11-S12.

Table S3. Model diagnostics for M1 to M4

Model	N	Parameters	Rank	Full rank	Status
M1_Network	3380	4	4	True	standard_logit_ok
M2_Organisation	3185	10	10	True	standard_logit_ok
M3_Fully_Adjusted	2414	12	12	True	standard_logit_ok
M4_State_FE	2267	49	49	True	Convergence warning (see Section S3); estimates retained for sensitivity use only

Table S4. Variance inflation factors, Model 2

Term	VIF
Ownership: Voluntary non-profit - Private	2.86
Ownership: Proprietary	2.02
Ownership: Voluntary non-profit - Other	1.63
Ownership: Government - Local	1.60

Ownership: Voluntary non-profit - Church	1.55
Hospital type: Critical Access Hospitals	1.14
Vendor-network participation	1.13
HIO participation	1.10
National-network participation	1.10

Table S5. Variance explained by principal component

Component	Variance explained	Cumulative variance
PC1	38.8%	38.8%
PC2	22.4%	61.2%
PC3	20.7%	81.9%
PC4	18.1%	100.0%

Table S6. Principal component loadings

Indicator	PC1	PC2	PC3	PC4
HIO participation	0.451	0.788	-0.110	-0.406
National-network participation	0.558	-0.012	-0.426	0.712
Vendor-network participation	0.487	-0.091	0.859	0.131
Current TEFCA participation	0.498	-0.609	-0.263	-0.558

Table S7. Leave-one-component-out correlations

Indicator omitted	Spearman rho with full index
HIO participation	0.948
National-network participation	0.928
Vendor-network participation	0.888
Current TEFCA participation	0.897

Table S8. Random Forest classification performance (held-out test set)

ROC-AUC	Accuracy	Precision	Recall	F1
0.676	0.651	0.495	0.622	0.551

Table S9. Random Forest feature importance

Predictor	Relative importance
National-network participation	61.9%
Vendor-network participation	28.1%
HIO participation	9.9%

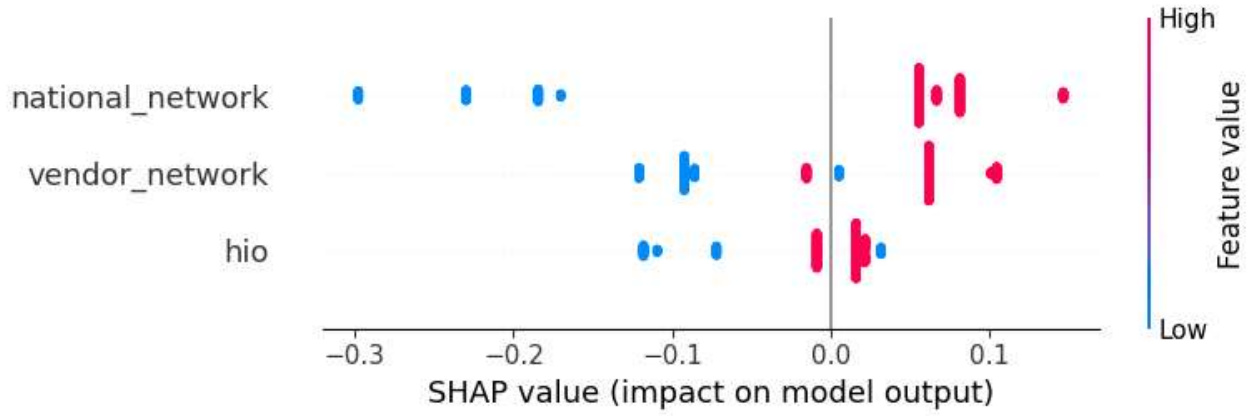


Figure S1. SHAP summary plot for the Random Forest model predicting TEFCA participation (national-network, vendor-network, and HIO participation; held-out test sample, n = 500).

Table S10. Missingness by variable group

Missingness rate	Number of variables	Representative variables
9.88%	1	pi_met
2.72%	38	cms_facility_name, cms_zip_code, cms_state, countyparish, and 34 more
2.07%	11	n_chpl_id, n_product_database_id, pi_state, pi_year, and 7 more

Note. The variable missing at 9.88 percent (pi_met) reflects hospitals without a matched Promoting Interoperability record; the 2.72 percent and 2.07 percent groups reflect hospitals without a matched CMS or Promoting Interoperability record, respectively, consistent with the linkage rates in Table 2.

Table S11. L2-regularised sensitivity analysis of Model 4 (C = 1.0)

Predictor	Conventional M4 OR	L2 M4 OR	Direction preserved	Rank preserved
HIO participation	1.28	1.26	Yes	Yes
National-network participation	4.09	3.92	Yes	Yes
Vendor-network participation	2.02	2.03	Yes	Yes

Note. L2 M4 used the same complete-case sample as conventional M4 (N = 2,267). L2 estimates are a robustness analysis, not conventional maximum-likelihood inference; p-values and confidence intervals are therefore not reported.

Table S12. L2-regularised M4 odds ratios across penalty strengths

C (inverse penalty strength)	HIO OR	National-network OR	Vendor-network OR
0.1 (strongest penalty)	1.20	3.13	1.94
0.5	1.25	3.79	2.02
1.0 (reported above)	1.26	3.92	2.03

2.0	1.27	4.01	2.02
10.0 (weakest penalty)	1.28	4.08	2.02

Note. The ordering national-network participation greater than vendor-network participation greater than HIO participation held at every penalty strength tested.