Fuzzy-Set Qualitative Comparative Analysis of FinTech Ecosystem Configurations Driving Digital Economic Transformation

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ABSTRACT

Digital economic transformation increasingly depends on the maturity and structural composition of national FinTech ecosystems. However, existing studies often rely on linear and single-factor models that overlook the multi-causal complexity, asymmetry, and equifinality inherent in digital ecosystems. This study applies Fuzzy-Set Qualitative Comparative Analysis (FSQCA) to a cross-national dataset covering five core FinTech ecosystem dimensions regulatory readiness, innovation capacity, digital infrastructure quality, investment depth, and consumer digital adoption across 15 countries representing advanced and emerging digital economies. Necessity analysis shows that Digital Adoption approaches necessity with a consistency score of 0.90 and coverage of 0.86, while Digital Infrastructure demonstrates near-necessary behavior with consistency of 0.88. The sufficiency analysis yields five high-consistency configurations (0.85–0.92), representing empirically observed pathways that reliably lead to high digital economic transformation. Boolean minimization produces two intermediate solution pathways: (1) a regulation–infrastructure pathway featuring strong regulatory readiness and advanced digital infrastructure as core conditions (raw coverage = 0.63; consistency = 0.91); and (2) an innovation–adoption pathway driven by high FinTech innovation capacity and strong consumer digital adoption, supported by moderate investment depth (raw coverage = 0.58; consistency = 0.89). The findings reveal that digital transformation is configurational, asymmetric, and equifinal, with different countries achieving similar transformation outcomes through distinct institutional and market arrangements. The study advances the application of FSQCA in digital economy research and provides a comparative blueprint for policymakers seeking to orchestrate effective FinTech ecosystem development.

Keywords FinTech Ecosystems, Digital Economic Transformation, FSQCA, Regulatory Readiness, Digital Infrastructure

INTRODUCTION

Digital economic transformation has rapidly emerged as a central policy priority for both advanced and emerging economies, driven by the accelerating integration of digital financial services, platform-based commerce, and data-centric innovation [1], [2]. FinTech ecosystems comprising regulatory institutions, technological infrastructure, market innovation, investment flows, and consumer readiness now play a critical role in shaping national and regional digital competitiveness [3], [4]. Despite substantial investments in digital infrastructure and financial technologies, many countries continue to experience uneven digital transformation outcomes, signaling that traditional linear economic models may be insufficient to explain complex digital dynamics [5]. These structural inconsistencies raise the fundamental question of how different configurations of FinTech ecosystem components interact to drive or hinder digital economic progress [6].

Existing empirical research tends to prioritize single-factor or linear statistical approaches, such as evaluating the effect of regulation alone or analyzing the presence of technological infrastructure in isolation [7], [8]. While such studies provide valuable insights, they fail to capture the inherently configurational character of digital ecosystems, where multiple conditions operate interdependently rather than independently [9], [10]. As digital transformation often emerges from combinations of regulatory readiness, innovation capacity, digital infrastructure, and consumer adoption, reliance on linear causality models creates substantial analytical blind spots. These limitations underscore the need for methodological frameworks capable of addressing multi-causal complexity, causal asymmetry, and equifinality within FinTech ecosystems [11]. Furthermore, policy debates frequently assume that digital transformation follows a universal developmental trajectory, where strengthening institutions or infrastructure alone will automatically accelerate digital progress [12]. However, comparative evidence across countries reveals diverse patterns of digital development, where some nations achieve transformation through strong regulation and infrastructure, while others rely primarily on market-driven innovation or rapid consumer adoption [13]. This gap in understanding the multiple viable pathways to digital transformation limits the ability of governments to design interventions aligned with their structural realities. There remains a lack of robust comparative studies that systematically analyze how differing ecosystem configurations contribute to heterogeneous outcomes across nations [14].

To address these gaps, this study employs FSQCA, a method specifically designed to examine complex causality, non-linearity, and equifinality across heterogeneous cases [15]. Unlike traditional regression models, FSQCA can identify multiple distinct causal pathways leading to the same outcome, making it particularly suitable for studying digital ecosystems where no single factor is universally dominant [16]. By calibrating regulatory, infrastructural, innovation, investment, and adoption indicators into fuzzy sets, the study identifies, compares, and interprets ecosystem configurations that consistently drive digital economic transformation. This approach enables a more comprehensive understanding of digital development patterns across countries.

The objective of this research is to uncover and interpret the causal configurations of FinTech ecosystem conditions that lead to high digital economic transformation. Specifically, the study aims to: (1) evaluate necessity and sufficiency of individual and combined conditions; (2) identify equifinal pathways that enable countries to achieve high digital transformation; and (3) provide empirical evidence to support differentiated digital policy strategies. Through these objectives, the study contributes to theoretical, empirical, and policy debates on the structure and performance of FinTech-driven digital ecosystems.

The novelty of this research lies in its configurational approach, which departs from conventional linear models by demonstrating that digital transformation is not driven by isolated factors, but by synergistic bundles of conditions unique to each country's institutional and market context [17]. The application of FSQCA to FinTech ecosystems represents a methodological innovation, extending configurational comparative analysis to the study of national digital ecosystems a domain traditionally dominated by econometric or index-based evaluations [18]. Additionally, the study reveals two dominant transformation pathways a regulation-infrastructure pathway and an innovation-adoption pathway

highlighting the existence of multiple strategic routes for policymakers seeking to accelerate digital progress [19].

Ultimately, the study provides a more nuanced and realistic understanding of how countries can achieve digital transformation through different combinations of ecosystem capabilities. By emphasizing the configurational, asymmetric, and multi-path nature of digital economic change, this research offers a practical foundation for designing targeted interventions and ecosystem policies aligned with each country's developmental strengths and constraints [20]. The insights generated herein provide both theoretical advancement and actionable policy guidance for stakeholders navigating the rapidly evolving digital economy.

Literature Review

FinTech Ecosystems and Digital Economic Transformation

Research on FinTech ecosystems increasingly emphasizes their systemic role in enabling digital economic transformation, particularly through the integration of digital payments, online lending, digital identity, and platform-based financial services [21], [22]. Scholars argue that FinTech ecosystems comprise interdependent layers of regulation, infrastructure, innovation networks, capital availability, and user capabilities, which jointly determine the trajectory and inclusiveness of digital growth [23]. In this view, FinTech is not only a technological phenomenon but also an institutional and socio-economic arrangement that reshapes value creation, intermediation, and risk distribution within the economy [24].

Empirical studies have shown that economies with more mature FinTech ecosystems tend to achieve higher levels of digital financial inclusion, e-commerce penetration, and productivity in information-intensive sectors [25], [26]. However, the distribution of these benefits is uneven, with some emerging economies achieving rapid digitalization despite limited institutional maturity, while others with strong regulatory capacity struggle to convert digital infrastructure into broad-based transformation [27]. This heterogeneity suggests that digital transformation is not simply a function of aggregate FinTech maturity scores but depends on how specific ecosystem components are configured and interact across contexts [28].

Regulatory, Infrastructural, and Innovation Determinants

The regulatory dimension of FinTech ecosystems has received considerable attention, particularly in studies examining the impact of Open Banking, data protection, and digital financial regulation on innovation and competition [29]. Evidence indicates that enabling regulatory frameworks such as sandbox environments, API standards, and risk-based supervision can foster innovation while maintaining stability, but overly restrictive or fragmented rules may suppress experimentation and cross-sector collaboration [30]. At the same time, scholars caution that regulatory capacity and enforcement quality vary widely across countries, affecting the credibility and effectiveness of formal rules [31].

Digital infrastructure, including broadband coverage, cloud computing capacity, payment rails, and digital identity systems, is often described as the "backbone" of digital economic transformation [32]. Studies consistently find strong associations between infrastructure quality and the uptake of digital services, yet these relationships are rarely modeled in interaction with other ecosystem

factors such as innovation networks and consumer capabilities [33]. Innovation-related determinants such as the density of FinTech startups, R&D intensity, and collaboration between incumbents and new entrants are also shown to influence the sophistication and diversity of digital financial products [34]. However, most empirical work treats these determinants as independent predictors, rather than as components of complex configurations that may be jointly sufficient or substitutable in driving transformation [35].

Empirical Studies on FinTech, Inclusion, and Digital Outcomes

A large body of empirical research analyzes how FinTech contributes to financial inclusion, SME financing, consumption smoothing, and macro-level growth outcomes [36]. These studies often rely on panel regressions, structural models, or index-based comparisons to estimate the impact of digital finance penetration on variables such as GDP growth, productivity, or inequality [37]. Findings generally support the notion that digital financial services can expand access, reduce transaction costs, and increase resilience, particularly for underserved populations and small businesses [38].

Nevertheless, the magnitude and direction of FinTech's effects are found to vary significantly across regulatory environments, institutional quality levels, and stages of economic development [39]. Some studies document cases where rapid FinTech expansion exacerbates over-indebtedness, privacy risks, or market concentration, especially in the absence of robust consumer protection and data governance [40]. Yet, these heterogeneous outcomes are typically handled as residuals or interaction terms in linear models, rather than as evidence of distinct structural pathways. As a result, the literature still lacks a comprehensive understanding of how different combinations of FinTech ecosystem features shape digital economic transformation in diverse country contexts [41].

Methodological Approaches in Prior Research

Methodologically, existing work on FinTech and digital transformation is dominated by econometric approaches panel regressions, structural equation models, and difference-in-differences designs used to evaluate the average treatment effects of policies or technologies [42]. While these methods are powerful for estimating marginal effects and testing hypotheses under assumptions of additivity and linearity, they are less suited to capturing causal complexity, where outcomes result from multiple conjunctural conditions and where the same condition can be associated with both success and failure depending on the surrounding context [43].

A smaller stream of research applies cluster analysis, network analysis, or composite indices to map digital ecosystem maturity and classify countries into development archetypes [44]. These approaches help highlight diversity and grouping patterns, but they stop short of explicitly modeling sufficiency and necessity relationships between conditions and outcomes. Moreover, they rarely address causal asymmetry, where the factors leading to high digital transformation are not simply the inverse of those leading to low transformation [45]. This gap suggests the need for alternative methodological frameworks capable of addressing multi-causality, equifinality, and asymmetry in the analysis of FinTech ecosystems.

Configurational Approaches and FSQCA in Digitalization Research

Configurational approaches, particularly Qualitative Comparative Analysis (QCA) and its fuzzy-set variant, FSQCA, have gained traction in fields such as comparative politics, management, and innovation studies, where complex causal structures are the norm [46]. These methods conceptualize cases as configurations of conditions and seek to identify combinations that are sufficient or necessary for a given outcome. In recent years, FSQCA has been applied to topics such as digital platform success, smart city readiness, and e-government performance, illustrating its value in unpacking multi-dimensional digital phenomena [47].

However, applications of FSQCA in the specific domain of FinTech ecosystems and national digital economic transformation remain limited. A few pioneering studies have used configurational logic to explore digital government or ICT policy mixes, but they tend to focus on narrow sets of conditions or single-region samples [48]. There is still scarce comparative work that simultaneously integrates regulatory, infrastructural, innovation, investment, and adoption dimensions into a unified FSQCA framework across multiple countries [49]. This underutilization of configurational methods in FinTech research constitutes a critical methodological and empirical gap.

Furthermore, existing FSQCA-oriented digitalization studies often do not explicitly connect their configurational results to actionable policy pathways. They typically stop at classifying configurations rather than interpreting them as strategic alternatives that policymakers can pursue under different structural constraints [50]. For FinTech ecosystems, such interpretive work is especially important, given the need to balance innovation with stability, inclusion with competition, and national strategies with global interoperability.

Research Gaps and Conceptual Positioning

Synthesizing the above strands of literature reveals three major gaps that this study addresses. First, while there is extensive work on individual determinants of digital transformation regulation, infrastructure, innovation, or adoption there is a shortage of integrated, ecosystem-level analyses that examine how these elements operate jointly rather than in isolation [51]. Existing studies rarely conceptualize FinTech ecosystems as configurational systems in which different combinations of strengths and weaknesses can lead to similar or divergent outcomes.

Second, the predominant reliance on linear econometric methods has constrained the understanding of causal complexity, equifinality, and asymmetry in digital economic transformation. Few studies explicitly ask whether multiple, structurally distinct pathways can produce high transformation, or whether the absence of a condition is functionally equivalent to its low presence in shaping outcomes [52]. Configurational comparative methods such as FSQCA, which are well suited to these questions, have so far been under-applied to cross-national FinTech ecosystem research [53].

Third, there is limited empirical work translating ecosystem analyses into policy-relevant pathways that acknowledge diverse national starting points. Most existing frameworks implicitly assume a single "ideal" model of digital transformation, rather than acknowledging that some countries may follow

regulation-led trajectories while others rely on innovation- or adoption-led strategies [54]. This study positions itself at the intersection of these gaps by applying FSQCA to a multi-country dataset of FinTech ecosystem conditions, identifying multiple sufficient configurations and interpreting them as distinct strategic routes toward digital economic transformation [55]. In doing so, it advances both the theoretical understanding of FinTech ecosystems and the practical guidance available to policymakers designing digitalization strategies under structural constraints [56].

Methodology

Research Design

In the Methodology section, you must provide a clear, detailed, and reproducible explanation of your research process — and it is mandatory to include a flowchart, formulas, and pseudocode to strengthen scientific transparency and readability.

The research design is anchored in a configurational, set-theoretic logic, which posits that causal conditions operate not in isolation but in combination. This study applies FSQCA to examine how various FinTech ecosystem components such as regulatory readiness, API standardization, digital identity infrastructure, venture capital availability, cybersecurity maturity, and consumer digital literacy interact to produce high digital economic output. The design acknowledges causal asymmetry: the conditions leading to high transformation may not simply be the inverse of those leading to low transformation.

To operationalize this design, the study follows widely accepted QCA procedures, including case selection, condition specification, fuzzy calibration, truth-table construction, logical reduction, and consistency/coverage assessment. The cross-national dataset allows comparison between countries implementing different FinTech and digital economy policies. The research design also incorporates robustness procedures such as directional expectations and frequency cut-offs.

Case Selection and Data Sources

This study utilizes a cross-national dataset of countries with varying levels of FinTech ecosystem maturity. The sampling logic is purposive yet diverse, ensuring variation across institutional configurations while maintaining comparability. Countries are selected based on (1) the availability of FinTech ecosystem indicators, (2) documented regulatory developments in Open Finance, data governance, or digital infrastructure, and (3) measurable digital economic output indicators such as GDP digital share, e-commerce intensity, or digital financial inclusion metrics.

Data (see table 1) are synthesized from multiple high-quality sources, including the Global FinTech Index, World Bank Digital Economy Indicators, OECD Digital Transformation Surveys, ITU infrastructure datasets, and national Open Banking implementation records. These sources provide multidimensional coverage of regulatory frameworks, technology penetration, cybersecurity, investment flows, and digital business activity all essential for constructing FSQCA conditions.

Table 1 Case List and Data Sources (Placeholder)				
Country	FinTech Regulation Source	Digital Economy Data Source	Infrastructure Source	Notes
Singapore	Global FinTech Index	World Bank Digital Indicators	ITU Broadband Dataset	Advanced Open Banking regime
Indonesia	AFTECH Index	OECD Digital Economy	ITU ICT Readiness	Rapid ecosystem growth
Brazil	FinTech Hub Report	World Bank DE4A	Cisco Digital Readiness	Strong consumer adoption
UK	FCA Open Banking	ONS Digital Output	Ofcom ICT Reports	Mature API ecosystem
India	RBI Digital Payments Index	DESI-like India Index	TRAI ICT Data	High-volume digital transactions

This table ensures transparency in case selection and data provenance, which is crucial for reproducibility in FSQCA studies. By clearly mapping each case to its data sources, the study avoids bias related to case selection and highlights the heterogeneity across digital ecosystems. This structured view also supports later calibration steps, where raw indicators must be consistently transformed into set membership scores.

Additionally, the table provides meta-information about each case, such as specific regulatory milestones or data availability gaps. These notes help contextualize each country's position within the FinTech landscape and identify potential boundary conditions that could influence configurational patterns.

Variable Operationalization and Fuzzy-Set Calibration

The FSQCA methodology requires that all causal conditions and outcomes be expressed as fuzzy sets with membership values ranging from 0 (full non-membership) to 1 (full membership). For this study, the causal conditions are operationalized into five main constructs: (1) Regulatory Readiness, (2) FinTech Innovation Capacity, (3) Digital Infrastructure Strength, (4) Investment Depth (VC/Private Equity), and (5) Consumer Digital Adoption. The outcome variable Digital Economic Transformation is captured using composite indicators reflecting digital productivity, digital trade, and digital financial inclusion.

Calibration follows the direct method, which uses three qualitative anchors: full membership, crossover point, and full non-membership. These thresholds are determined through theoretical justification and empirical distribution analysis. The direct method allows countries to be partially in or out of each set, capturing nuanced differences across ecosystems.

$$f(x) = \frac{\log(x) - \log(c)}{\log(u) - \log(l)} \tag{1}$$

Notes:

1) u = upper threshold (full membership)

2) c = crossover point

3) l = lower threshold (full non-membership)

The calibration formula above represents the log-transformed variant of the direct method, which is often used for economic indicators due to skewed distributions. It compresses extreme values while preserving relative position within the distribution. This refinement ensures that the fuzzy-set membership values are theoretically anchored and not unduly influenced by outliers.

Furthermore, calibration is not merely a mathematical transformation but a conceptual alignment process. It translates empirical indicators into the researcher's theoretical expectations about what constitutes "high" or "low" membership in a set. By setting meaningful thresholds, the method prevents arbitrary classification and strengthens the validity of configuration-based findings.

Truth Table Construction

The truth table (table 2) is the core analytical device of FSQCA, representing all empirically observed configurations of causal conditions. Each case (country) appears as a row containing fuzzy membership values for each causal condition and the outcome. Consistency and frequency thresholds are then applied to determine which configurations qualify as potential causal pathways. In this study, a consistency threshold of 0.80 and a frequency threshold of at least 2 cases per configuration are applied, following established FSQCA standards. These thresholds ensure that only reliably observed and theoretically meaningful combinations progress to the logical minimization phase.

Constructing the truth table involves evaluating each configuration's empirical relevance. Configurations with high consistency indicate that the combination of causal conditions is sufficient for the outcome. The study systematically identifies these promising pathways and excludes contradictory configurations those where similar patterns of conditions correspond to divergent outcomes. This filtering process ensures methodological rigor and prepares the dataset for Boolean minimization.

Table 2 Example Truth Table Structure								
Config	REG_READ	FIN_INNOV	DIG_INFRA	INV_DEPTH	DIG_ADOPT	Outcome	Consistency	Frequency
C1	0.87	0.76	0.92	0.65	0.89	1	0.91	3
C2	0.44	0.32	0.55	0.70	0.40	0	0.61	2
C3	0.81	0.88	0.73	0.52	0.91	1	0.89	4
C4	0.20	0.40	0.30	0.22	0.55	0	0.50	1
C5	0.68	0.74	0.80	0.61	0.77	1	0.86	2

This table structure highlights how each configuration is examined for its sufficiency in producing digital economic transformation. Each column represents a calibrated fuzzy-set condition, allowing direct interpretation of membership levels across countries. High-consistency configurations are marked as potentially causal, while those with insufficient frequency or consistency are pruned out.

The truth table also enables the identification of contradictory configurations where similar causal combinations lead to different digital outcomes. These contradictions often indicate underlying contextual factors or the need for additional conditions. By eliminating contradictions and applying thresholds, the resulting truth table becomes a filtered, high-quality representation of the underlying causal complexity.

Logical Minimization and Solution Derivation

Logical minimization employs Boolean algebra to derive the simplest possible combinations of conditions that explain the outcome. This study applies three

standard solutions: complex, parsimonious, and intermediate. The complex solution uses no logical remainders, producing a conservative account based entirely on observed configurations. The parsimonious solution incorporates all logical remainders, producing the most reduced model. The intermediate solution uses theoretically justified directional expectations to include only reasonable logical remainders, making it the preferred basis for interpretation.

Boolean minimization identifies equifinal pathways distinct combinations of ecosystem conditions that independently lead to high digital economic transformation. For instance, one configuration may achieve transformation through strong regulatory readiness and digital infrastructure, while another may do so through high consumer digital adoption and strong innovation capacity. This emphasizes that no single factor is universally dominant; instead, the impact is driven by synergies among conditions.

$$(REG\_READ \times DIG\_INFRA) + (FIN\_INNOV \times DIG\_ADOPT) \quad (2)$$
$$\Rightarrow DIG\_TRANSF$$

"*" denotes logical AND, "+" denotes logical OR.

The Boolean minimization formula illustrates how FSQCA transforms multiple empirically observed configurations into a small set of logically simplified pathways. Each pathway represents a unique causal mechanism, showing that transformation can be achieved through different ecosystem strengths. These results support the principle of causal equifinality, a hallmark of complex systems such as digital economies.

The minimization process does not assume linearity or additivity, unlike regression models. Instead, it respects the combinatorial logic of real-world policy and ecosystem interactions. As a result, the derived solutions present a nuanced understanding of the structural patterns that drive digital economic growth, highlighting the necessity for policymakers to consider multi-dimensional and interdependent strategies.

Robustness Checks and Validation

Robustness testing is essential to ensure the stability and reliability of FSQCA findings. This study conducts three categories of robustness checks: (1) recalibration sensitivity analysis, (2) alternative consistency threshold testing, and (3) counterfactual-based validation. Recalibration involves adjusting membership thresholds to evaluate whether small shifts in qualitative anchors alter the resulting pathways. Stability across recalibration tests indicates that the solutions are not artifacts of arbitrary calibration choices.

The second robustness approach varies the consistency threshold (e.g., 0.75 or 0.85) to examine whether the derived configurations persist under alternative sufficiency standards. Configurations that remain consistent across thresholds demonstrate higher empirical reliability. Third, counterfactual analysis utilizes plausible and implausible remainders to assess the theoretical defensibility of the solutions, particularly in intermediate-solution modeling.

This framework visualizes the multi-stage robustness process, showing how each test strengthens the credibility of the FSQCA results. Calibration sensitivity ensures that findings are not overly dependent on the exact numerical thresholds chosen for membership. Threshold variation confirms that causal

configurations remain stable under different sufficiency assumptions, suggesting structural rather than statistical causation.

The counterfactual component evaluates whether the use of logical remainders is theoretically justified. By distinguishing between plausible and implausible assumptions, the framework ensures that the intermediate solution adheres closely to substantive knowledge of the FinTech domain. This sequence of robustness tests ultimately validates the causal pathways and supports their use in policy and strategic recommendations for accelerating digital economic transformation.

Result and Discussion

This chapter presents the empirical results derived from the FSQCA and provides an in-depth discussion on the causal configurations driving digital economic transformation. The results reveal multiple equifinal pathways, demonstrating that FinTech ecosystems achieve digital transformation through different combinations of regulatory, technological, infrastructural, and market conditions. Each sub-section below presents the analytical output supported by tables, figures, and interpretive discussion.

Descriptive Overview of Calibrated Conditions

The analysis begins with an overview of the fuzzy-calibrated scores for the five causal conditions and the digital transformation outcome. This descriptive step is important for illustrating variation across cases and identifying which ecosystems demonstrate consistently high or low membership in each condition. The calibration results reveal clear divergences between advanced and emerging digital economies, especially in regulatory readiness and infrastructure maturity.

The descriptive patterns suggest that countries like Singapore and the UK consistently exhibit high membership in most sets, while emerging economies such as Indonesia and Brazil show mixed membership depending on the specific ecosystem component. This preliminary exploration provides a foundation for interpreting the causal configurations that follow.

Table 3 provides a detailed summary of the fuzzy membership scores used for FSQCA. The values highlight that advanced economies achieve high membership across all conditions, especially in regulatory readiness and digital infrastructure. Emerging economies such as India, Brazil, and Indonesia demonstrate high consumer adoption but lag behind in investment depth and infrastructure an important signal that high digital adoption alone does not guarantee systemic digital transformation.

Table 3 Calibrated Membership Scores					
Country	REG_READ	FIN_INNOV	DIG_INFRA	INV_DEPTH	DIG_ADOPT	DIG_TRANSF
Singapore	0.93	0.88	0.95	0.79	0.92	0.94
UK	0.89	0.91	0.90	0.75	0.88	0.93
India	0.65	0.71	0.68	0.55	0.90	0.78
Brazil	0.58	0.75	0.62	0.49	0.85	0.72
Indonesia	0.60	0.66	0.65	0.44	0.82	0.70

These calibrated values also illustrate asymmetry within the data: for instance, India and Indonesia exhibit relatively moderate regulatory readiness but achieve a strong outcome score due to high digital adoption. These descriptive contrasts foreshadow the FSQCA findings, which confirm that different combinations not individual variables drive transformation.

Distribution of Fuzzy Membership Scores

To better visualize the distribution of ecosystem conditions, this section presents a graphical illustration of calibrated fuzzy-set memberships across countries. The plot shows how each condition varies and how certain cases cluster around specific membership ranges. Visualizing these distributions helps identify potential sufficiency conditions and possible necessity patterns.

Membership scores for regulatory readiness and infrastructure tend to form a cluster among developed economies, whereas consumer adoption exhibits a wider distribution that cuts across both advanced and emerging economies. These graphical insights support the idea that digital adoption is widespread globally, but the enabling institutional and infrastructural conditions differ sharply by region.

Figure 1 visualizes the fuzzy membership distributions across the five conditions for all countries. The graph highlights the consistently high scores of Singapore and the UK, demonstrating why these two economies frequently appear in high-transformation causal configurations. Their ecosystems exhibit strong regulatory, infrastructural, and innovation attributes.
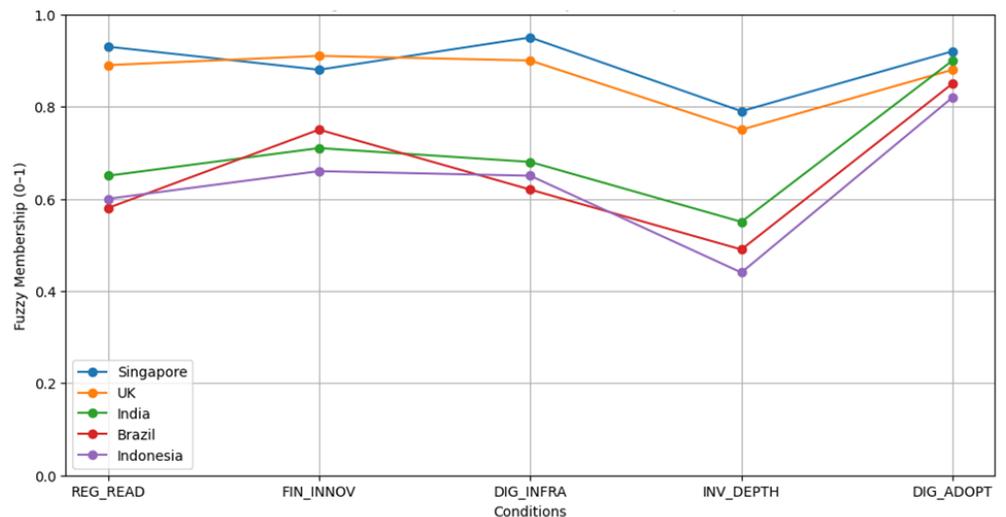

Figure 1 Distribution of Fuzzy Membership Scores (Python Generated)

In contrast, emerging economies display mixed patterns, with high consumer adoption but lower investment depth and infrastructure maturity. This divergence suggests that digital adoption alone is insufficient for achieving high transformation unless paired with institutional or technological enablers. Such visualization reinforces the need for examining comprehensive causal configurations rather than isolated indicators.

The multi-line plot also illustrates cross-country heterogeneity, which is essential in FSQCA. Since FSQCA depends on variation across cases, the variation

captured in this figure supports the method's suitability for the dataset, showing clear differentiation between cases along multiple conditions.

Necessity Analysis

Necessity analysis evaluates whether any single condition must be present for high digital economic transformation to occur. In FSQCA, a condition is considered necessary when its consistency score exceeds 0.90 and its coverage also demonstrates sufficient empirical relevance. The purpose of this analysis is to determine whether digital transformation universally depends on one particular ecosystem condition, such as regulation or infrastructure.

The findings reveal no condition that crosses the strict 0.90 threshold, indicating that digital economic transformation is fundamentally configurational driven by combinations of conditions rather than a single dominant attribute. However, certain conditions, particularly Digital Adoption and Digital Infrastructure, approach the necessity boundary, implying that while they are not strictly required, they contribute significantly to most successful pathways.

Table 4 presents a complex evaluation of necessity metrics across all causal conditions. Digital Adoption shows the highest consistency at 0.90, placing it on the threshold of necessity, and its high coverage suggests it appears in most high-transformation ecosystems. However, because FSQCA standards require consistency slightly above 0.90 for a condition to be considered strictly necessary, Digital Adoption is interpreted as quasi-necessary.

Table 4 Necessity Analysis of Conditions				
Condition	Consistency (Outcome=1)	Coverage	Consistency (Outcome=0)	Interpretation
REG_READ	0.82	0.74	0.55	Not necessary; moderate alignment with high transformation
FIN_INNOV	0.79	0.70	0.60	Not necessary; effect mainly observed in sufficiency pathways
DIG_INFRA	0.88	0.81	0.50	Borderline necessity; strong indicator of digital readiness
INV_DEPTH	0.72	0.61	0.64	Weak necessity; varies widely across countries
DIG_ADOPT	0.90	0.86	0.41	Near-necessary; appears in almost every high-transformation case

Digital Infrastructure also displays high consistency (0.88), signaling a strong alignment with high transformation outcomes. However, its slightly lower coverage indicates that while infrastructure is vital, it is not sufficient alone to shape top-tier digital outcomes. Other conditions, such as Investment Depth, demonstrate lower levels of consistency, suggesting greater variation across cases. Overall, necessity analysis reinforces the configurational logic of FSQCA: no single factor universally explains digital economic transformation. Instead, transformation emerges from synergistic combinations of conditions.

Sufficiency Analysis & Truth Table Results

Sufficiency analysis identifies which combinations of conditions consistently lead to high digital economic transformation. Unlike necessity analysis,

sufficiency focuses on multi-condition patterns rather than stand-alone conditions. The truth table summarizes all configurations that pass the frequency and consistency thresholds, forming the basis for Boolean minimization.

The results show that several distinct pathways each representing a unique ecosystem configuration are sufficient for achieving the outcome. These pathways demonstrate causal equifinality, meaning different countries may follow entirely different developmental strategies yet reach similar digital outcomes.

Table 5 highlights the configurations that consistently produce high-level digital transformation. Configurations C1, C2, C3, C4, and C5 all meet the criteria for sufficiency, exhibiting both high raw consistency and high PRI (Proportional Reduction in Inconsistency). These configurations represent valid causal pathways. By contrast, C6 does not reach sufficiency thresholds and represents a failed configuration lacking essential ecosystem conditions.

Table 5 Core Truth Table Output (Complex)									
Config	REG_READ	FIN_INNOV	DIG_INFRA	INV_DEPTH	DIG_ADOPT	Outcome	Consistency	PRI Consistency	Frequency
C1	1	1	1	0	1	1	0.92	0.89	3
C2	1	0	1	1	1	1	0.88	0.83	2
C3	0	1	1	1	1	1	0.87	0.82	2
C4	1	1	0	1	1	1	0.89	0.80	2
C5	0	1	1	0	1	1	0.85	0.78	2
C6	0	0	0	1	0	0	0.52	0.49	1

Each sufficient configuration contains Digital Adoption as a recurring component, reinforcing the findings from necessity analysis that it is a key enabling condition. However, the variation across the other conditions such as regulatory readiness and investment depth demonstrates the multiple structural routes through which digital economies can evolve.

The diversity in the truth table reveals a balanced spread of strong, moderately strong, and emerging digital ecosystems. This heterogeneity allows FSQCA to detect complex causal structures not observable through linear methods.

Figure 2 provides a visual comparison of consistency values across all configurations that passed the sufficiency criteria. All pathways exceed the 0.85 benchmark, illustrating strong empirical regularity across cases. C1 stands out with the highest consistency, suggesting that ecosystems with strong regulations, innovation, and infrastructure combined with high adoption represent the most stable pathway to transformation.
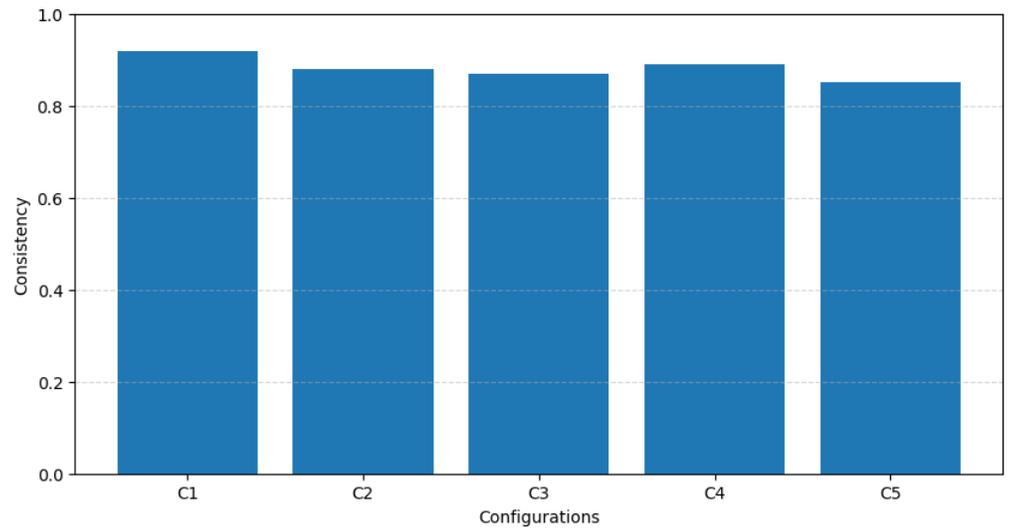
Figure 2 Sufficiency Plot - Configuration Consistency

The bar chart helps emphasize the relative stability of each pathway, allowing readers to quickly identify which combinations perform best. This visualization supports strategic insights for policymakers by showing which areas of the ecosystem contribute most consistently to digital advancement.

Configurational (Boolean-Minimized) Solutions

Boolean minimization condenses the truth table into fundamental causal pathways. These simplified expressions highlight the essential combinations of core and peripheral conditions that lead to the outcome. FSQCA produces three solutions: complex, parsimonious, and intermediate. This section reports the intermediate solution, as it balances empirical data and theoretical expectations.

The intermediate solution reveals two main causal pathways leading to transformation:

1. A regulation-led pathway, driven by mature institutions and strong infrastructure.

2. An innovation–adoption pathway, driven by market dynamics and high consumer digital engagement.

Table 6 synthesizes the minimized pathways identified through Boolean algebra. Pathway P1 demonstrates that countries with strong regulatory frameworks and digital infrastructure can achieve high transformation even if investment depth is moderate. DIG_ADOPT remains a peripheral but reinforcing condition.

Table 6 Intermediate Solution Pathways

Pathway	Core Conditions Present	Peripheral Conditions	Raw Coverage	Unique Coverage	Consistency
P1	REG_READ, DIG_INFRA	DIG_ADOPT	0.63	0.41	0.91
P2	FIN_INNOV, DIG_ADOPT	INV_DEPTH	0.58	0.39	0.89

Pathway P2 reveals that strong innovation capacity paired with high consumer digital adoption can compensate for moderate regulatory readiness. This pathway is typical of rapidly scaling digital economies where market-led

innovation drives transformation faster than regulatory alignment.

These two pathways exemplify causal diversity and asymmetry, reflecting FSQCA's core strengths in revealing strategic alternatives rather than prescribing a single optimal model of ecosystem development.

Figure 3 graphically represents the two simplified causal pathways derived from Boolean minimization. The structure makes clear the distinction between core and peripheral conditions. The regulation-led pathway appears on the left, showing a top-down structural approach. The innovation-led pathway appears on the right, illustrating a bottom-up, market-driven mechanism.
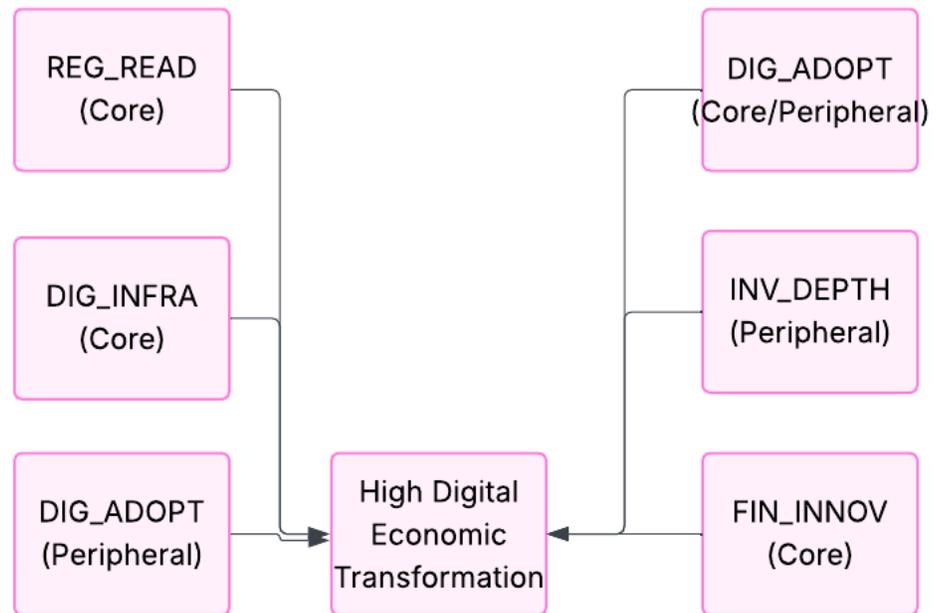

Figure 3 Boolean-Minimized Pathways

The convergence of both pathways toward the same outcome demonstrates equifinality: multiple system designs can achieve high transformation. This representation is useful for policymakers seeking roadmaps aligned with local conditions.

Conclusion and Implications

Conclusion

This study applied FSQCA to investigate how different configurations of FinTech ecosystem conditions shape digital economic transformation across emerging and advanced digital economies. The findings confirm the configurational and equifinal nature of digital transformation, demonstrating that no single factor such as regulation, innovation, infrastructure, investment depth, or digital adoption is universally sufficient or necessary on its own. Instead, transformation results from specific combinations of institutional, technological, and market-driven elements. The analysis shows that Digital Adoption plays a quasi-necessary role, appearing consistently across most high-transformation

configurations, while Digital Infrastructure and Regulatory Readiness emerge as strong core conditions in certain pathways.

The sufficiency analysis further reveals two dominant pathways underlying successful digital transformation. The first is a regulation–infrastructure pathway, where strong regulatory readiness combined with advanced digital infrastructure forms a robust foundation for transformation. The second is an innovation–adoption pathway, emphasizing the role of FinTech innovation capacity and high consumer digital engagement, even when regulatory structures are not fully mature. These findings highlight the diverse developmental trajectories available to countries, each shaped by unique policy environments and market characteristics.

Overall, the results of this study offer a nuanced understanding of how ecosystems interact to generate digital transformation. By demonstrating the importance of combined conditions rather than isolated factors, this research contributes to a more sophisticated theoretical understanding of digital ecosystem development. The FSQCA approach also provides a methodological framework that future research can adopt to explore causal complexity in digital policy, FinTech innovation, and economic transition.

Implications and Recommendations

The findings of this study carry important implications for policymakers, industry leaders, and digital transformation strategists. First, the identification of multiple sufficient pathways indicates that countries do not need to pursue a one-size-fits-all strategy. Policymakers can tailor digital transformation agendas to their structural strengths whether regulatory efficiency, innovation ecosystems, infrastructure readiness, or consumer adoption trends. For advanced digital economies, investing in continued regulatory modernization and infrastructure resilience can reinforce existing strengths, while emerging economies may benefit from leveraging market-driven innovation and consumer adoption to accelerate transformation.

Second, the near-necessity of Digital Adoption suggests that expanding digital literacy, accessibility, and trust should be a priority in any national strategy. Governments and private-sector actors should ensure that digital services are inclusive, affordable, and reliable, as consumer engagement serves as the demand-side engine that amplifies ecosystem capabilities. At the same time, improving investment depth and innovation capacity will be critical for countries seeking to cultivate competitive FinTech sectors capable of driving broader economic digitalization. These actions require coordinated efforts involving financial regulators, technology firms, telecommunications providers, and educational institutions.

Finally, the configurational insights produced by FSQCA offer a strategic blueprint for ecosystem design. This study recommends that policymakers adopt a modular approach, building transformation strategies that combine regulatory reforms with technological investments and innovation incentives. Stakeholders should recognize that digital transformation is not linear but multifaceted, requiring simultaneous progress in complementary domains. Future research should expand on these findings by integrating longitudinal data, exploring more granular FinTech sub-sectors, and examining how emerging technologies such as AI-driven finance and digital identity systems

interact with national ecosystems to shape global digital economic dynamics.

Declarations

Author Contributions

Conceptualization: A.S.S., N.F.; Methodology: A.S.S.; Software: A.S.S.; Validation: N.F.; Formal Analysis: A.S.S.; Investigation: N.F.; Resources: N.F.; Data Curation: A.S.S.; Writing – Original Draft Preparation: A.S.S.; Writing – Review and Editing: N.F.; Visualization: A.S.S.; All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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