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Dual-Platform Enablement and Triple-Chain Leapfrog Growth: A Configurational Study of Autonomous Driving Complementors in China

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Abstract

Existing accounts of platform-mediated complementor growth rest on two limiting assumptions: that platform enablement constitutes a homogeneous environmental input and that firm growth is a unitary outcome. This double simplification obscures how distinct platform provisions generate qualitatively different forms of firm transformation. This study asks which combinations of mechanistically distinct platform enablement types and internal strategic response capabilities activate which forms of leapfrog growth among complementor firms operating under dual institutional governance. We employ fuzzy-set Qualitative Comparative Analysis (fsQCA) on survey data from 374 complementor firms in China's autonomous driving platform ecosystem. Five antecedent conditions are examined across two dimensions: platform enablement, comprising rule-based enablement (RE) and business platform enablement (BPE); and strategic response capabilities, comprising network linkage capability (NLC), organizational ambidexterity (OA), and policy responsiveness (PR). Three outcome variables capture three non-reducible leapfrog dimensions: technology-chain (TL), value-chain (VL), and institutional-chain (IL) transitions. A reverse-causality robustness check and a common-method-bias assessment corroborate the validity of findings. The analysis identifies equifinal configurational pathways with distinct dominant logics across the three chains. Technology-chain transitions are predominantly network-linkage-driven; value-chain transitions are policy-responsiveness-anchored; institutional-chain transitions exhibit genuine equifinality between network-linkage and policy-responsiveness pathways, both requiring dual-platform enablement as a universal structural precondition. No single enabling condition or capability suffices; leapfrog growth is irreducibly configurational and causally asymmetric. The study offers a dual-enablement, three-chain configurational framework for understanding platform-mediated firm growth under dual institutional governance. For complementor firms, findings support dimension-selective capability investment over uniform accumulation strategies. For platform orchestrators, differentiated governance design calibrated to specific complementor upgrading trajectories outperforms homogeneous resource provisioning. For policymakers, institutionalized consultative channels linking private platform governance with public regulatory processes are recommended to facilitate coordinated digital industrial transformation.



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1. Introduction

Autonomous driving complementor firms in China today face a strategic paradox that existing growth frameworks struggle to explain (Wareham et al., 2014; Kretschmer et al., 2022). On one hand, participation in dominant platform ecosystems—Baidu Apollo, Huawei ADS, and others—has become a de facto precondition for survival. Firms that remain outside these ecosystems lose access to annotated datasets, simulation environments, certification channels, and regulatory visibility. On the other hand, the mere act of joining a platform does not translate into growth. Industry observers and managers repeatedly report a puzzling pattern: firms with comparable technical foundations and similar levels of platform engagement achieve dramatically different growth trajectories. Some leapfrog into core complementor positions within two to three years, while others remain peripheral suppliers despite sustained investment. Practicing managers, therefore, confront three concrete decisions that existing theory offers little guidance on: which internal capabilities to prioritize given a specific type of platform engagement; whether to pursue technology upgrading, market repositioning, or regulatory participation as the primary growth lever; and how to sequence investments in rule-compliance versus resource-absorption activities. Our study addresses these questions by identifying the configurational conditions under which platform enablement translates into leapfrog growth along three distinct chains: technology, value, and institutional. In this study, technology-chain transition (TL) refers to the firm-level shift from customized, scene-specific technical solutions to standardized modular architectures integrated by ecosystem partners; value-chain transition (VL) refers to the shift from project-based fulfillment to hub-positioning with pricing authority in inter-organizational value networks; and institutional-chain transition (IL) refers to the progression from passive regulatory compliance to active co-construction of industry standards and governance frameworks. These three constructs are operationalized in Section 4.2 and formally tabulated in Table 1.

Consider how the competitive landscape of China's autonomous driving industry has changed over the past five years. In 2020, most complementor firms still competed largely on proprietary technical components sold directly to automotive OEMs. By 2024, the same firms increasingly depended on a small number of platform orchestrators—Baidu Apollo, Huawei ADS, and Mobileye—for access to annotated datasets, simulation environments, certification credentials, and regulatory visibility (iResearch Consulting Group, 2024; McKinsey & Company, 2025). This five-year shift has elevated these platform orchestrators from technology suppliers to de facto rule-setters (Mukhopadhyay & Bouwman, 2019; Weber et al., 2024). They now define technical standards, API protocols, safety certification frameworks, and data-sharing rules that determine which complementary firms gain access, visibility, and growth opportunities within the ecosystem.

Within this new arena, a puzzle has become hard to ignore: firms with superior core technologies frequently fail to achieve value leapfrogging. RoboSense, a LiDAR manufacturer, successfully expanded by adapting to Baidu Apollo's computational framework. Horizon Robotics transitioned from chip designer to core computing architecture supplier by co-developing open toolchains with multiple platform partners (iResearch Consulting Group, 2024; ResearchAndMarkets, 2024). Yet numerous equally capable firms remain trapped at the peripheral level, unable to convert technical excellence into ecosystem-level influence. This pattern reveals a fundamental inadequacy in the traditional hidden champion growth model—designed for stable, closed markets where niche specialization and incremental accumulation suffice—which does not capture how growth works in open platform ecosystems where network effects, institutional complexity, and non-linear competitive dynamics govern firm trajectories (Simon, 2009; Teece et al., 1997).

Scholarly attempts to explain complementor growth within platform ecosystems are constrained by two critical limitations. First, existing research treats platforms as homogeneous enabling environments, failing to distinguish systematically between their dual roles as rule-setters and resource-providers (Lechner et al., 2023; Weber et al., 2024). Conflating these distinct mechanisms produces theoretically underdifferentiated accounts of how platforms shape firm trajectories. Second, prevailing methodological approaches rely primarily on regression-based analyses of net effects, which rest on linearity assumptions ill-suited to the configurational nature of capability-based growth processes (Fiss, 2011; Ragin, 2008). They cannot capture equifinal pathways—in which qualitatively different combinations of enabling conditions and capabilities produce identical leapfrog outcomes—nor can they model the asymmetric causal logic in which success conditions differ structurally from failure conditions.

Research Gap and Research Problem. Taken together, the two limitations above expose a single conceptual under-determination at the heart of the platform-growth literature: existing accounts cannot specify which platform inputs activate which forms of firm transformation. We frame the research problem accordingly: How do mechanistically distinct types of platform enablement combine with internal strategic response capabilities to activate qualitatively different forms of leapfrog growth among complementor firms in dual-governance platform ecosystems? Answering this question requires both a disaggregated theorization of platform enablement (Section 2.2) and a configurational analytical strategy (Sections 2.4 and 4.3).

China's autonomous driving industry provides an analytically distinctive empirical context for this research problem. Unlike most digital platform markets, it operates under a dual institutional logic in which private platform governance—proprietary technical standards, ecosystem certification systems, and data-sharing protocols—interacts continuously with public governance: ministerial testing regulations, municipal demonstration area policies, and national standardization initiatives. This dual architecture is simultaneously private and public, technical and regulatory, creating a governance complexity that renders single-mechanism explanations of firm growth inadequate and exemplifies the rise in platforms as quasi-institutional rule-setters in digital transformation contexts (Wareham et al., 2014; Kretschmer et al., 2022).

This study advances two conceptual moves that depart from dominant theorizations of platform-mediated growth. First, it disaggregates platform enablement along a rule–resource axis: rule-based and business platform enablement are mechanistically distinct inputs that the existing literature largely treats as interchangeable—a conflation that forecloses the question of which enablement type drives which form of transformation. Second, it decomposes leapfrog growth into three non-collapsible transition dimensions—technology-chain, value-chain, and institutional-chain—each anchored at a qualitatively different level of firm organization. Together, these moves transform the guiding question from “does platform enablement drive firm growth” to “which configurations of enablement and capability activate which forms of leapfrog transformation”—a reformulation that is inherently configurational and that motivates the analytical approach adopted below.

To address these gaps, this study employs fuzzy-set Qualitative Comparative Analysis (fsQCA) on survey data from 374 complementary firms across China's autonomous driving platform ecosystem. We operationalize five antecedent conditions spanning two dimensions—platform enablement (RE, BPE) and strategic response capabilities (NLC, OA, PR)—and three leapfrog outcome variables (TL, VL, IL). The results identify equifinal configurational pathways for each leapfrog dimension, demonstrating that different combinations of conditions drive qualitatively distinct forms of value escalation.

This study makes three contributions. First, it disaggregates platform enablement into rule-based and resource-based dimensions that activate qualitatively different capability pathways, replacing the homogeneous-environment assumption with a dual-enablement account. Second, it constructs a three-capability–three-transition matching model that supplants single-mediator accounts of capability-based growth. Third, it offers a configurational governance lens for platform-mediated firm growth under dual institutional governance, operationalized through equifinal and asymmetric pathways that conventional net-effect methods cannot recover. These contributions are elaborated in Section 7.1.

The remainder of the paper is organized as follows. Section 2 reviews platform ecosystem research, the dual conceptualization of platform enablement, hidden champion and leapfrog growth theory, and configuration theory as the analytical foundation. Section 3 develops the dual-enablement, three-chain theoretical framework and articulates three configurational propositions. Section 4 describes the survey data, variable measurement, and fsQCA procedure. Section 5 reports necessary conditions analysis, truth-table configurations for all three outcomes, and two robustness checks: reverse-causality falsification and common-method-bias assessment. Section 6 discusses the configurational findings, including a cross-study comparison with prior platform and configurational research. Section 7 concludes with theoretical contributions, practical implications, limitations, and directions for future research.

2. Literature Review

Before reviewing the substantive literature, we map the theoretical architecture that organizes the four bodies of scholarship invoked throughout this paper, since their co-presence may otherwise appear to signal theoretical eclecticism rather than deliberate design. The four bodies occupy three functionally distinct roles. Hidden champion theory (Simon, 2009) operates at the phenomenon level: it supplies the descriptive vocabulary—narrow-niche specialization, capability intensity, and non-linear market ascent—that characterizes the class of complementor firms whose growth trajectories constitute the subject of inquiry. Dynamic capabilities theory (Teece et al., 1997; Eisenhardt & Martin, 2000) and platform governance theory (Gawer, 2021; Chen et al., 2021) jointly occupy the explanatory level: the former accounts for the firm-internal mechanisms through which sensing, seizing, and reconfiguring capabilities are mobilized; the latter accounts for the external structural conditions through which platform orchestrators shape the possibility frontier available to complementors. Neither theory alone is sufficient; their integration is precisely what enables the study to link internal capability bundles with external platform-mediated enablement conditions. Configuration theory (Meyer et al., 2017; Fiss, 2011; Furnari et al., 2021) operates at the methodological-logic level: it supplies the set-theoretic and combinatorial reasoning that allows equifinal, asymmetric, and conjunctural causal structures to be recovered from the data without imposing the linearity and additivity assumptions embedded in regression-based analyses. These three roles—phenomenon delineation, causal explanation, and analytical logic—are complementary by design rather than competing by accident. The remainder of Section 2 reviews each theoretical body in turn.

2.1. Platform Ecosystems and Digital Governance in Emerging Economies

Platform ecosystems have emerged as the dominant organizational form in digitally transformed industries, representing a fundamental departure from traditional market structures. Building on Adner's (2017, p. 43) foundational conceptualization of the ecosystem as structure, platform ecosystems are defined as multilateral coordination mechanisms in which a central technical architecture aligns platform owners, complementors (sup-

ply side participants), and end-users around a shared value proposition. This tripartite structure—core platform infrastructure, multi-homing participant communities, and governance entities managing ecosystem rules—differs fundamentally from bilateral market relationships, because value creation depends on cross-side network effects in which the utility of each participant group increases with the scale and diversity of other groups (Jacobides et al., 2018; Cennamo, 2021). Tiwana's (2013) influential treatise on platform ecosystems further demonstrates that governance architecture—the system of rules, incentives, and controls that platforms deploy to manage complementor relationships—is inseparable from technical architecture in determining ecosystem performance. Platforms do not merely coordinate transactions; they constitute institutional environments that define what is technically possible, commercially viable, and strategically legitimate for complementary firms (Constantinides et al., 2018).

Beyond their transactional role, platforms have evolved into what Chen et al. (2021) characterize as meta-organizations: institutional actors that govern entire fields of economic activity through private rule systems. Platforms construct technical standards, certification bodies, data-sharing protocols, and revenue-allocation mechanisms that function as quasi-regulatory instruments with mandatory compliance effects on ecosystem participants (Chen et al., 2021). This evolution from market intermediaries to institutional rule-setters has particular significance in emerging economies, where private platform governance frequently intersects and sometimes competes with public institutional frameworks. Gawer (2021) demonstrates that platform boundaries are not fixed technical parameters but strategically contested institutional artifacts, as platforms expand their governance scope to internalize value-creating activities previously performed by independent complementors. The governance implications are profound: complementary firms in platform ecosystems must navigate not only market competition but also platform-imposed institutional constraints that shape the range of admissible strategies.

In China's autonomous driving industry, this dual governance dynamic manifests with exceptional clarity. Baidu Apollo, Huawei ADS, and comparable platform orchestrators define technical interfaces, safety certification requirements, and data annotation standards that function as private governance codes with binding effects on complementors. Simultaneously, the Chinese government deploys an extensive public governance apparatus—the Ministry of Industry and Information Technology's pilot city designation system, national standardization committees, and municipal demonstration area regulations—that creates a complementary, and occasionally competing, institutional layer. This "platform-enabled, policy-driven" configuration (Chen et al., 2021) constitutes a natural experiment in dual institutional governance, providing an analytically rich context for examining how firms navigate the intersection of private platform rules and public regulatory frameworks. The resulting institutional complexity makes China's autonomous driving ecosystem particularly suitable for investigating the configurational mechanisms through which platform enablement drives leapfrog growth.

2.2. Platform Enablement: Rule-Based Enablement and Business Platform Enablement

The concept of platform enablement—the processes through which platforms activate and amplify the capabilities of complementary firms—requires analytical disaggregation to capture its distinct operational mechanisms. Platform enablement is conceptually distinct from platform governance, which refers to the comprehensive system of rules and incentives that platforms use to manage the entire ecosystem (Chen et al., 2021). Platform enablement specifically concerns the mechanisms through which platforms enhance what complementary firms can do and achieve within the ecosystem. Boudreau's (2010) seminal distinction between 'granting access' and 'devolving control' provides the foundational

framework: platforms can enable complementors by opening technical interfaces (access-based enablement) or by transferring decision-making authority over product development (control-based enablement). We extend this framework by differentiating rule-based enablement and business platform enablement as two analytically distinct mechanisms with qualitatively different effects on complementor capability development.

Rule-based enablement (RE) refers to the systematic institutional structuring through which platforms reduce uncertainty for complementors by establishing clear technical standards, transparent interface protocols, verifiable compliance frameworks, and participatory rule-making channels. Drawing on institutional theory (Scott, 1995) and platform governance research (Tiwana, 2014; Hagiwara & Wright, 2019), we argue that platforms exercise rule-based enablement by defining the ‘possibility frontier’ of complementor action: what technical solutions are admissible, what data formats are compatible, what safety certification levels are required. In the autonomous driving context, rule-based enablement manifests in Apollo’s open platform architecture specifications, which define computational interfaces that sensor manufacturers must satisfy to achieve ecosystem integration; Huawei’s ADS compatibility certification system, which establishes testing protocols for algorithm providers; and cross-platform data format standardization efforts that reduce the cost of multi-homing. This form of enablement operates primarily through reducing institutional uncertainty, legitimizing complementor strategies, and directing organizational attention toward productive innovation domains (Ofe & Sandberg, 2022).

Business platform enablement (BPE) refers to tangible provisioning through which platforms supply complementors with data assets, computational infrastructure, market access channels, and capital resources. We adopt the term in the sense articulated by Gawer and Cusumano (2002) and Tiwana (2014), who conceptualize business platforms as architectures that enable third-party complementors through resource provisioning rather than rule-setting. This conceptualization is further grounded in resource orchestration theory (Sirmon et al., 2011) and platform ecosystem research (Ceccagnoli et al., 2012; Jacobides et al., 2018). In autonomous driving, BPE is exemplified by Baidu Apollo’s annotated road-test datasets, Huawei’s HiSilicon computational platform, and platform-mediated introductions to commercial clients. Unlike rule-based enablement, which operates through institutional channels such as standards and certification, BPE operates through direct resource transfer. The two enablement types, therefore, activate different capability-development trajectories: RE stimulates internal reconfiguration, whereas BPE stimulates capacity scaling through external resource absorption.

Critically, rule-based and business platform enablement activate different capability-development pathways. Rule-based enablement primarily stimulates internal organizational capability reconfiguration by providing the institutional clarity needed for simultaneous exploration and exploitation; firms can pursue radical technical innovation knowing what governance boundaries they must not transgress. Business platform enablement primarily activates network-level capability development by supplying the raw material (data, compute, market connections) that inter-organizational collaboration transforms into value. Existing literature has not systematically distinguished these two enablement types or empirically examined their differentiated effects on distinct leapfrog dimensions, a gap this study addresses.

The selection of capability–enablement pairings examined in this study is not post hoc; it follows directly from the mechanistic distinctions established above. Rule-based enablement is theoretically aligned with network linkage capability because both operate through the logic of institutionalized inter-organizational coordination: RE defines the governance boundaries within which complementors may connect and collaborate, while NLC determines how effectively a firm exploits those boundaries to occupy hub positions in col-

laboration networks (Tiwana, 2014; Ofe & Sandberg, 2022). Business platform enablement is theoretically aligned with policy responsiveness because both operate through the logic of resource-mediated institutional legitimacy: BPE supplies the tangible assets—data, compute, market access—that platforms provision to preferred partners, while PR determines how effectively a firm converts that resource access into co-governance standing vis-à-vis public regulatory processes (Sirmon et al., 2011; Chen et al., 2021). Organizational ambidexterity occupies a structurally distinct position: rather than being aligned primarily with either enablement type, it functions as an internal amplifier of the exploration–exploitation balance that both RE and BPE perturb. RE creates a stable institutional frontier that allows exploitation without sacrificing exploratory latitude; BPE supplies external resources that reduce the internal slack constraints on exploration. Organizational ambidexterity is the capacity that converts these dual perturbations into simultaneous adaptive responses (Eisenhardt & Martin, 2000; Schilke et al., 2018). These three theoretically grounded pairings motivate the configurational propositions developed in Section 3, and they ensure that the antecedent conditions entered into the fsQCA analysis are selected on prior theoretical grounds rather than empirical convenience.

2.3. Hidden Champions and Leapfrog Growth in Platform Ecosystems

Simon's (2009) foundational theory of hidden champions identifies a category of firms—typically mid-sized, narrowly specialized, globally oriented—that achieve dominant market positions in narrow niches through sustained investment in proprietary capabilities and deep customer relationships, largely invisible to broader competitive scrutiny. The theory's central premise is a stable competitive equilibrium: specialized capabilities generate niche advantages, which generate premium revenues, which fund further specialization. This self-reinforcing mechanism assumes a relatively stable competitive environment where the sources of advantage are internal, and the market structure is transparent. These assumptions are severely violated in platform-mediated ecosystems. Platform ecosystems introduce network effects that can rapidly amplify or marginalize any firm's market position based on ecosystem embeddedness rather than technical capability alone. A laser radar manufacturer with superior hardware specifications may be marginalized if its interface is incompatible with the dominant platform's computational framework, while a technically inferior competitor achieves rapid scale because it prioritized ecosystem integration (Simon, 2009; Gawer & Cusumano, 2002; Cusumano et al., 2019). The traditional accumulation logic cannot explain this non-linear dynamic.

We conceptualize leapfrog growth as a structural process of ecological niche repositioning—the fundamental transformation of a firm's functional role within the platform ecosystem—driven by specific configurations of external enablement and internal capability. Leapfrog growth is not incremental performance improvement measured in financial metrics; it is a categorical transition from one ecosystem role to another, characterized by discontinuity, irreversibility, and systemic coupling effects. This conceptualization draws on Yap et al.'s (2022) framework of niche escalation in technology ecosystems, Ritzer's (2012) analysis of platform-mediated institutional positioning, Helfat and Raubitschek's (2018) account of how dynamic and integrative capabilities enable non-linear value capture in digital platform-based ecosystems, and Cennamo's (2021) analysis of how platform multiplicity generates competitive discontinuities that systematically undermine the incremental accumulation logic on which traditional niche theory rests. We operationalize leapfrog growth across three chains that capture distinct dimensions of ecosystem role transformation. Technology-chain transition (TL) captures the shift from customized, scene-specific solutions toward standardized modular architectures that are proactively integrated by third parties, from 'scenario-dependent adaptor' to 'rule-contributing ar-

chitect' status. Value-chain transition (VL) captures the shift from project-based order fulfillment toward hub-positioning in value creation networks, with pricing authority and revenue-sharing participation. Institutional-chain transition (IL) captures the shift from passive regulatory compliance toward active co-construction of industry standards and governance frameworks, from 'license applicant' to 'standard co-drafter'.

The three transition dimensions have distinct theoretical groundings. Technology-chain transition corresponds to the 'sensing and seizing' mechanisms in Teece et al.'s (1997) dynamic capabilities framework: the recognition of technological opportunity and the mobilization of resources to capitalize on it (Teece et al., 1997; Teece, 2018). Value-chain transition corresponds to the complementor-to-orchestrator progression identified in platform ecosystem research, where firms that successfully leverage platform network effects to build multi-party service delivery networks achieve disproportionate value appropriation (Eisenmann et al., 2011; McIntyre & Srinivasan, 2017). Institutional-chain transition corresponds to North's (1990) concept of institutional entrepreneurship: the capacity to shape the formal and informal rules that govern an institutional field. Together, the three transitions constitute the 'hard-soft-authority' tripod of leapfrog growth: technical standardization capability, commercial ecosystem influence, and institutional co-governance capacity.

Existing hidden champion research focuses predominantly on product-market advantages, offering no systematic analysis of platform ecosystem embeddedness as a driver of non-linear growth. Research on platform complementors examines participation and performance but has not analyzed the mechanisms of structural role transitions. Dynamic capabilities research establishes the general importance of reconfiguration capabilities but lacks context-specific operationalization for platform ecosystems. This study fills these converging gaps by examining how specific configurations of platform enablement and strategic response capabilities drive the three-dimensional leapfrog growth process.

2.4. Configuration Theory and the Rationale for fsQCA

Configuration theory holds that organizational phenomena cannot be adequately explained by the net effects of individual variables but must be understood as emergent properties of specific combinations of multiple conditions (Meyer et al., 2017; Misangyi et al., 2017). The central theoretical claim is that conditions exhibit interdependence—substitution, complementarity, and suppression—such that the effect of any single condition depends fundamentally on which other conditions are simultaneously present or absent. In the context of platform enablement and leapfrog growth, this theoretical insight is empirically consequential: the effect of rule-based enablement on technology-chain transition is not a fixed coefficient but varies systematically based on whether organizational ambidexterity is present or absent. No regression coefficient can capture this configurational dependency because regression models decompose effects into additive components, treating conditions as independent contributors rather than as elements of coherent wholes. The 'three-capability—three-transition' matching hypothesis that motivates this study is fundamentally a configurational claim that requires configurational methods (Greckhamer et al., 2018; Park et al., 2020).

Fuzzy-set Qualitative Comparative Analysis (fsQCA) provides the appropriate analytical framework for three reasons. First, the leapfrog pathways this study investigates involve multiple, simultaneously necessary conditions—INUS conditions (insufficient but non-redundant parts of an unnecessary but sufficient condition)—that cannot be decomposed into independent net effects without misrepresentation. In autonomous driving platform ecosystems, rule-based enablement and organizational ambidexterity together constitute a sufficient condition for technology-chain transition, but neither is sufficient alone; regression analysis, by estimating conditional main effects, systematically misspeci-

fies this structure (Ragin, 2008; Fiss, 2011; Shao & Wang, 2025). Second, fsQCA explicitly accommodates equifinality—the existence of multiple distinct configurations that all produce the same outcome—which is theoretically predicted for all three transition dimensions. Technology-chain transition may be achievable through a rule enablement–ambidexterity pathway and through an alternative business platform enablement–network linkage pathway; regression analysis would either estimate an averaged coefficient that misrepresents both pathways or require the specification of all possible interaction terms, which becomes computationally and interpretively intractable. Third, fsQCA models causal asymmetry: the logical independence of conditions sufficient for high outcomes and conditions sufficient for low outcomes. The absence of rule enablement does not mechanically produce a low technology-chain transition; failure configurations may be driven by entirely different condition combinations. Regression analysis conflates these asymmetric causal structures by estimating symmetric coefficients (Schneider & Wagemann, 2012).

With $N = 374$, this study applies fsQCA to a sample substantially larger than the small- N studies in which the method originated. Greckhamer et al. (2018), in a comprehensive methodological review, demonstrate that fsQCA is both valid and advantageous for medium-to-large sample research when the theoretical question is inherently configurational rather than about average net effects. Larger samples provide more reliable calibration distributions, enabling more precise specification of the threshold values that distinguish full membership, crossover, and full non-membership in each fuzzy set. The configurational logic remains epistemologically appropriate regardless of sample size when the research question concerns ‘which combinations of conditions are sufficient for an outcome’ rather than ‘how strongly does each condition affect an outcome on average’ (Greckhamer et al., 2018, p. 485).

2.5. Synthesis of Prior Studies and Research Gap

The foregoing review traverses four interlocking bodies of scholarship, and it is worth pausing to consolidate what the literature collectively establishes and where it collectively falls short.

The first strand of work has clarified the structural grammar of platform ecosystems. Adner’s (2017) conceptualization of the ecosystem as a multilateral coordination structure defined the vocabulary of platform owners, complementors, and end-users around shared value propositions, while Jacobides et al. (2018) demonstrated that ecosystem-level value creation is fundamentally shaped by complementarities and modular interdependencies that no single participant controls. These foundational contributions established that complementor behavior cannot be analyzed in isolation from the architectural properties of the platform environment in which it is embedded. Gawer (2021) extended this insight by showing that platform boundaries are not fixed technical parameters but strategically contested institutional artifacts: platforms continuously redefine the perimeter of what complementors may do, how, and on what terms. Chen et al. (2021) pushed this argument further, reconceptualizing platforms as meta-organizations that exercise quasi-regulatory authority over their ecosystems through private rule systems, a characterization that carries particular weight in the context of China’s autonomous driving industry, where private platform codes interact with state regulatory frameworks. Cennamo (2021) added the competitive dimension, demonstrating that platform multiplicity and multi-homing dynamics reshape competitive logics in ways that standard product-market frameworks cannot capture.

A second strand has examined the mechanisms through which platforms enable or constrain complementor capability development. Boudreau (2010) provided the seminal empirical demonstration that platform openness operates through at least two analytically

distinct channels—granting technical access and devolving decision-making control—and that these channels produce meaningfully different innovation effects. [Ofe and Sandberg \(2022\)](#) extended this line of inquiry into contemporary digital ecosystems, showing that rule-based platform governance has generative effects on complementor behavior that operate independently of direct resource provisioning. Together, these contributions establish a strong *prima facie* case for disaggregating platform enablement rather than treating it as a homogeneous environmental input. Yet no prior study has operationalized this disaggregation as a dual-input construct—rule-based enablement and business platform enablement—and empirically examined how the two activate different capability-development pathways leading to different forms of firm transformation.

A third strand has examined how complementors escalate their ecological position within platform ecosystems. [Yap et al. \(2022\)](#) provided a conceptual framework for understanding how firms transition from peripheral to central positions in technology ecosystems, offering important scaffolding for the leapfrog growth concept developed in this study. Research in adjacent administrative science domains, such as [Kankam-Kwarteng et al.'s \(2026\)](#) examination of how entrepreneurial ecosystem policies mediate SME sustainability, further confirms that ecosystem-level governance conditions materially shape firm growth trajectories across varied institutional settings. What remains absent, however, is a systematic decomposition of firm growth into qualitatively distinct transition dimensions. Existing complementor research treats growth as a unitary or composite performance construct, collapsing technology upgrading, market repositioning, and institutional co-construction into a single measure that obscures their different enabling logics.

A fourth strand has developed the methodological toolkit for configurational analysis in organizational research. [Misangyi et al. \(2017\)](#) advanced the neo-configurational perspective, establishing equifinality and causal asymmetry as foundational principles for the study of complex organizational phenomena. [Park et al. \(2020\)](#) demonstrated that fsQCA is not only applicable to digital platform contexts but methodologically advantageous when the research question concerns causal recipes rather than average net effects, a precedent this study extends to a substantially larger survey sample.

Taken together, these four strands leave three gaps that are individually important and collectively critical. First, no prior study has systematically distinguished rule-based enablement from business platform enablement as mechanistically non-interchangeable inputs, operationalized both as antecedent conditions, and empirically examined how each activates different capability-development pathways within the same analytical framework. Second, leapfrog growth in platform ecosystems has not been decomposed into the technology-chain, value-chain, and institutional-chain transitions that capture its qualitatively distinct loci of change; the resulting conflation suppresses precisely the variation that makes the phenomenon theoretically interesting. Third, the literature on platform-mediated complementor growth has relied almost exclusively on regression-based net-effect methods, which are structurally unable to recover the equifinal, asymmetric, and conjunctural causal structures that the configurational nature of capability-based growth processes demands. The present study addresses all three gaps simultaneously, and Section 3 develops the theoretical framework and configurational propositions that follow from this diagnosis.

3. Theoretical Framework

This study's theoretical framework integrates dynamic capabilities theory ([Teece et al., 1997](#); [Eisenhardt & Martin, 2000](#)) with platform governance theory ([Gawer, 2021](#); [Chen et al., 2021](#)) to conceptualize leapfrog growth as a configurational process unfolding across three stages: external enablement activation, internal capability mediation, and contextual amplification. This framework diverges from prior mediation-focused accounts

of capability-based growth in two important respects. First, it explicitly disaggregates the external enabling environment into rule-based and resource-based dimensions, recognizing that these operate through qualitatively distinct mechanisms. Second, it treats the outcome variable as three-dimensional—technology-chain, value-chain, and institutional-chain transitions—rather than as a unitary performance construct, reflecting the theoretical claim that different forms of leapfrog growth require different enabling-capability configurations.

The five antecedent conditions in the framework are organized around two complementary theoretical pillars, whose internal structure reflects the capability–enablement pairings established in Section 2.2. Platform enablement conditions (RE, BPE) represent structural-level inputs that originate outside the firm and reflect the quality and character of the platform’s governance architecture: RE operates through institutional rule-setting that defines the possibility frontier of admissible complementor action, while BPE operates through direct resource provisioning that supplies the raw material for capability scaling. Strategic response capability conditions (NLC, OA, PR) represent firm-level dynamic capabilities that determine how effectively external enablement is absorbed, converted, and deployed: NLC is the relational mechanism through which RE-defined governance boundaries are converted into hub positions; PR is the institutional mechanism through which BPE-provisioned resources are converted into co-governance standing; OA is the internal amplifier that allows firms to respond adaptively to both enablement types simultaneously. This inside-out and outside-in integration follows the logic of complementarity in resource-based strategy: external enablement without the corresponding internal capability generates unrealized structural potential, while internal capability without the requisite external enablement lacks the ecosystem-level scaffolding necessary for leapfrog transitions. Neither pillar alone is sufficient; it is the theoretically matched configurations that jointly activate each form of leapfrog growth.

The configurational logic of the framework makes three theoretical predictions that distinguish it from linear mediation models. First, the technology-chain transition is predicted to require a rule enablement–organizational ambidexterity configuration. Rule enablement provides institutional clarity about what technical standards are valued and how compliance is assessed. In contrast, organizational ambidexterity enables firms to simultaneously deepen existing capabilities (exploitation) and explore beyond current standards (exploration). This tension produces the standardized yet innovative architectures characteristic of technology-chain leaders. Second, value-chain transition is predicted to require a business platform enablement–network linkage configuration: platform-provided resources (data, compute, market access) supply the raw material for value creation, while network linkage capability converts these inputs into multi-party collaborative networks that produce hub-level value appropriation. Third, institutional-chain transition is predicted to require a rule enablement–policy responsiveness configuration: rule-based platform enablement embeds firms in private governance processes, while policy responsiveness capability enables them to simultaneously navigate and influence public governance: the dual institutional competence required for standard co-construction. These predictions are tested through fsQCA, which allows for the simultaneous examination of equifinal pathways and the identification of configurations not anticipated by the primary theoretical model.

Configurational Propositions. Consistent with configurational research traditions (Fiss, 2011; Misangyi et al., 2017), this study develops configurational propositions rather than symmetric net-effect hypotheses, as the former are epistemologically appropriate for set-theoretic analyses that identify equifinal sufficient conditions rather than estimate average causal coefficients. The three theoretical predictions developed above are accordingly restated as formal configurational propositions, each anchored in a primary theoretical tradition and carrying an explicit derivation chain that links theoretical mechanism to

empirical prediction. We present the propositions here in propositional form; they are re-examined alongside the corresponding chain-specific empirical results in the discussion.

Proposition 1 (Technology-Chain Transition). *Technology-chain transition is driven by a configuration in which rule-based enablement is combined with network linkage capability, with organizational ambidexterity functioning as an amplifying condition. The derivational logic proceeds as follows. Dynamic capabilities theory establishes that technical architecture reconfiguration depends on “sensing-and-seizing” coordination: firms must simultaneously recognize emergent technical standards and mobilize the relational resources necessary to embed those standards in inter-organizational architectures (Teece et al., 1997). Platform governance theory specifies that standards diffusion is inherently a multi-actor process: technical interfaces gain adoption not through unilateral superiority but through governed ecosystem coordination (Tiwana, 2013). The conjunction of these two mechanisms implies that network linkage capability is the modal enabling capability for technology-chain transition: it is the organizational competence through which rule-based governance boundaries are converted into hub positions within standardized architectures. Organizational ambidexterity amplifies this configuration by allowing firms to deepen compliance-oriented exploitation while simultaneously exploring beyond current standards, producing the standardized yet innovative architectures that define technology-chain leadership.*

Proposition 2 (Value-Chain Transition). *Value-chain transition is principally enabled by a configuration in which business platform enablement is combined with policy responsiveness capability, with this pathway reflecting the primacy of resource-mediated institutional legitimacy in hub-position acquisition. The derivational logic is as follows. Institutional theory establishes that legitimacy—the perception that a firm’s actions are desirable and appropriate within a given institutional system—is a foundational prerequisite for acquiring preferential access to commercial partners and value-sharing arrangements (Scott, 1995). In dual-governance platform contexts, legitimacy is not solely market-derived; it accrues to firms that are visibly embedded in both private platform governance and public regulatory processes (Chen et al., 2021). Business platform enablement supplies the tangible resource base—datasets, compute infrastructure, market introductions—that elevates a firm’s ecosystem standing and signals its platform-certified status to potential commercial partners. Policy responsiveness capability determines how effectively the firm converts this elevated standing into active co-governance participation, which further amplifies commercial positioning by conferring the institutional authority associated with standard co-construction. The configuration thus operates through a resource-to-legitimacy-to-positioning chain that differs qualitatively from the coordination-based logic of Proposition 1.*

Proposition 3 (Institutional-Chain Transition). *Institutional-chain transition requires dual-platform enablement (both rule-based and business platform enablement) as a structural precondition, with network linkage capability and policy responsiveness functioning as equifinal strategic response mechanisms. The derivational logic draws on institutional entrepreneurship theory, which distinguishes between collective and individual pathways to rule co-construction: firms may participate in the co-authorship of institutional rules either through coalition-building across ecosystem actors (a network-based pathway) or through direct bilateral engagement with regulatory authorities (a policy-based pathway), and theory admits both as viable routes to the same institutional outcome (North, 1990; DiMaggio & Powell, 1983). The equifinality of these pathways is theoretically anticipated rather than empirically coincidental, and it is precisely the kind of causal structure that fsQCA is designed to detect and represent (Fiss, 2011). Dual-platform enablement constitutes the structural precondition because an institutional-chain transition requires simultaneous embeddedness in private platform governance (provided by RE) and access to the ecosystem resources that confer platform-legitimated standing (provided by BPE); neither enablement type alone supplies sufficient*

structural access to the governance processes in which institutional co-construction occurs. The Dual-Enablement, Three-Chain Configurational-Framework is described in Figure 1.

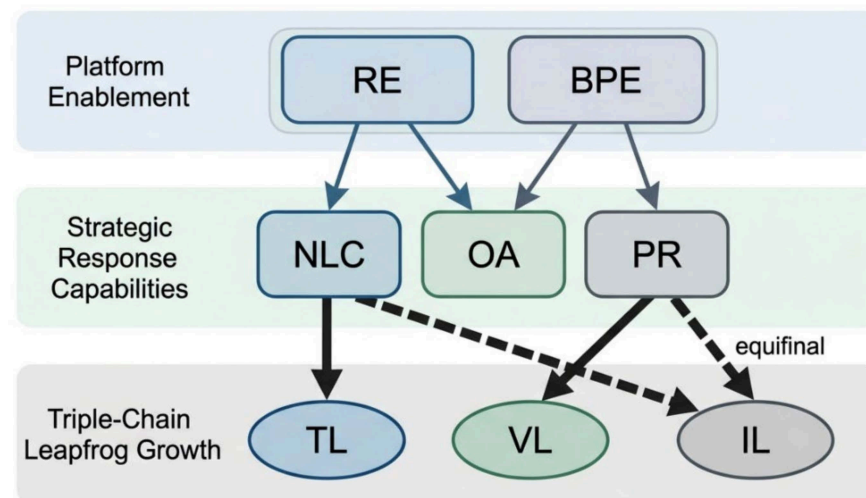


Figure 1. The Dual-Enablement, Three-Chain Configurational Framework. Note: RE = rule-based enablement; BPE = business platform enablement; NLC = network linkage capability; OA = organizational ambidexterity; PR = policy responsiveness; TL = technology-chain transition; VL = value-chain transition; IL = institutional-chain transition. Bold arrows indicate modal core conditions identified ex post in Section 5; dashed arrows indicate equifinal alternatives.

4. Data and Methodology

4.1. Data Collection

Given the rapid platformization of China's autonomous driving industry and the pivotal role of complementary firms in shaping platform ecosystem dynamics, this study draws on survey data from autonomous driving-related firms across China. The sample construction followed a stratified random sampling procedure, stratifying firms by geographic region (Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta, Central-Western pilot cities, and Northeast China) and supply chain position (perception layer, decision layer, execution layer, and system integration and application layer), ensuring proportional representation across all strata.

Research Context Justification. China's autonomous driving industry constitutes an analytically distinctive rather than merely empirically convenient setting for testing the dual-enablement, three-chain configurational framework, for three reasons that correspond directly to the theoretical structure of the study. First, the industry operates under dual institutional governance in a form that is unusually transparent and measurable: private platform orchestrators (Baidu Apollo, Huawei ADS) and public regulatory bodies (the Ministry of Industry and Information Technology, municipal pilot-zone authorities) issue partially overlapping yet partially competing rule sets, producing precisely the dual-governance condition our framework theorizes and rendering the distinction between rule-based and business platform enablement empirically visible rather than analytically stipulated. Second, the industry is at an early-maturation stage (2024–2026) in which technical standards, certification protocols, and pilot-program licenses remain actively under co-construction, meaning that complementors are currently navigating the full spectrum of enablement conditions—from nascent rule clarity to mature resource provisioning—rather than operating within a settled institutional regime. This temporal positioning preserves the variation in platform enablement conditions that a later-stage survey would likely truncate. Third, the prominence of state-led demonstration zones across geographically dispersed municipalities produces meaningful cross-firm variation in policy-responsiveness

exposure, a feature that is structurally absent from most digital platform settings in which public governance is either minimal or spatially uniform (De Reuver et al., 2018). Together, dual governance architecture, in-flux standardization, and policy-responsiveness variance make the Chinese autonomous driving complementor population a uniquely instructive empirical site. The scope conditions that follow from this context, and the corresponding boundaries on cross-context generalizability, are discussed in Section 7.3.

Data collection employed four complementary channels to maximize coverage and response quality: (1) industry associations and professional bodies, including the China Intelligent and Connected Vehicles Industry Innovation Alliance and regional automotive engineering societies; (2) national-level testing zones and industrial parks, such as the Beijing Yizhuang Advanced Autonomous Driving Demonstration Zone, the Shanghai Jiading National Intelligent Connected Vehicle Pilot Zone, and the Wuxi National Internet of Vehicles Pioneer Zone; (3) industry conferences and trade exhibitions held during the survey period; and (4) the research team's established academic-industry network in the new energy vehicle and platform economy sectors. For online questionnaires, firms were contacted by telephone to obtain consent prior to distribution by email, with a follow-up reminder issued three weeks after the initial invitation to non-responding firms. The stratified invitation list was assembled by cross-referencing the membership roster of the China Intelligent and Connected Vehicles Industry Innovation Alliance with the MIIT Pilot City Demonstration Program registry and regional automotive engineering society directories, ensuring that all five geographic strata and four supply chain layers were systematically represented in the sampling frame prior to randomized selection.

The sample construction process employed three exclusion criteria. Firms were excluded if (1) they did not constitute complementary enterprises within the autonomous driving platform ecosystem: firms providing key complementary products or services to platform operators across sensing, decision-making, execution, or system integration functions; (2) the respondent did not hold a position of department manager or above (including general managers/CEOs, deputy general managers/VPs, CTOs, strategy directors, and product leads); or (3) the questionnaire failed data quality screening, including incomplete responses on key scale items, incorrect answers to two embedded attention-check questions, stereotyped response patterns (fifteen or more consecutive identical ratings), or implausibly short completion times (under three minutes).

A total of 700 questionnaires were distributed between February and March 2026. Of the 520 returned (response rate: 74.29%), 146 were removed following quality screening—36 for incompleteness, 41 for attention-check failures, 28 for patterned responding, 18 for ineligible respondent seniority, and 23 for excessively rapid completion—yielding a final valid sample of 374 firms (effective response rate: 53.43%) spanning 14 provinces and municipalities across China. To ensure sample independence, the formal survey sample was verified as mutually exclusive from both the exploratory factor analysis pre-survey sample ($N = 152$, October–November 2025) and the reliability pre-test sample ($N = 112$, December 2025–January 2026) through cross-referencing of firm names and respondent contact details; no overlap was identified. The full 64-item questionnaire, in both its original Chinese form and English translation, is provided in Appendix B (Including Appendices B.1 and B.2) to support transparency and replicability.

To facilitate sample-composition transparency and confirm the analytical representativeness of the sample, we report the distribution across five dimensions. In terms of geographic coverage, the sample spans five regional clusters: the Yangtze River Delta (Shanghai, Jiangsu, Zhejiang, Anhui) accounts for 33.96% ($N = 127$), with Jiangsu contributing the largest provincial sub-sample ($N = 57$), reflecting the dense concentration of autonomous driving complementors in that province; the Beijing-Tianjin-Hebei cluster

accounts for 21.39% ($N = 80$), anchored in the Beijing Yizhuang Advanced Autonomous Driving Demonstration Zone and Zhongguancun pilot area; the Central-Western pilot cities (Hubei, Chongqing, Hunan, Sichuan) account for 20.86% ($N = 78$), all Ministry of Industry and Information Technology-designated fully driverless commercialization or vehicle-road-cloud integration pilot zones; the Pearl River Delta (Guangdong) accounts for 13.37% ($N = 50$); and the Northeast cluster (Jilin, Liaoning) accounts for 10.43% ($N = 39$). This distribution ensures that all principal regional hubs of China's autonomous driving industry are represented. In terms of primary business domain, the sample covers the main application segments of the autonomous driving complementor population: low-speed unmanned delivery (39.57%), campus logistics and inspection (36.10%), port and mining operations (21.66%), and other applications (2.67%), confirming substantive coverage across the functional diversity of the complementor ecosystem. In terms of firm size, the sample is distributed across the full size range: fewer than 50 employees (22.99%), 50–200 (22.46%), 201–500 (27.54%), and more than 500 (27.01%), with no single size category dominating. In terms of R&D intensity, over half of the sample (58.56%) allocates more than 5% of revenue to research and development (5–10%: 30.75%; above 10%: 27.81%), consistent with the technology-intensive character of autonomous driving hidden champion firms. In terms of platform ecosystem embeddedness, 64.71% of sample firms participate in national or provincial demonstration projects, 66.31% hold officially certified platform-partner status, and 47.59% are simultaneously embedded in two or more platform ecosystems, indicating that the sample carries sufficient variation in platform engagement depth to sustain the configurational analysis. Respondent-level characteristics further support data credibility: 71.12% of informants hold senior executive positions (General Manager/CEO, Deputy General Manager/VP, CTO, or Strategy Director), and 70.59% have been with their current firm for three to ten years, ensuring informants possess both organizational authority and sufficient institutional memory to report on platform enablement and capability conditions reliably. Full sample statistics are reported in Table A1 of Appendix A.

4.2. Variable Measurement

Complete item wording for all eight constructs, together with reverse-coding specifications, is reported in Appendix B. Given that all core constructs are deeply embedded in the institutionally dense and technically dynamic context of autonomous driving platform ecosystems, existing validated scales could not be directly applied. We developed original scales through a five-stage procedure: item generation via parallel deductive (28 theoretical references, 42 items) and inductive (217 grounded theory codes from multi-case interviews, 68 items) pathways; content validity assessment by an expert panel of five scholars and practitioners (75% inter-rater agreement threshold); scale purification via exploratory factor analysis (EFA) on a pre-survey sample of $N = 152$ (October–November 2025), eliminating four items with communalities below 0.50; reliability confirmation on an independent pre-test sample of $N = 112$ (December 2025–January 2026); and final construct validity verification through confirmatory factor analysis (CFA) on the formal survey sample ($N = 374$). All constructs satisfied established thresholds: Cronbach's $\alpha > 0.85$, composite reliability (CR) > 0.88 , average variance extracted (AVE) > 0.50 , and heterotrait–monotrait ratio (HTMT) < 0.85 .

Outcome variables. Leapfrog growth was operationalized as a three-dimensional second-order reflective construct capturing structural position transitions within the platform ecosystem. Technology-chain transition (TL; $\alpha = 0.910$, 7 items) measures transition from customized solutions toward standardized modular architectures integrated by third parties. Value-chain transition (VL; $\alpha = 0.812$, 4 items, following EFA purification) measures the shift from project-based fulfillment toward hub-positioning with pricing authority.

Institutional-chain transition (IL; $\alpha = 0.892$, 6 items) measures progression from passive compliance toward active co-construction of industry standards.

Condition variables. Rule enablement (RE; $\alpha = 0.902$, 7 items) captures perceived stability of technical standards, interface transparency, and participatory rule-making opportunities. Business platform enablement (BPE; $\alpha = 0.914$, 7 items) captures perceived provision of data, computation, toolkits, and market access. Network linkage capability (NLC; $\alpha = 0.905$, 7 items) captures the capacity to orchestrate complementary partners and occupy hub positions. Organizational ambidexterity (OA; $\alpha = 0.895$, 7 items) captures the capacity to simultaneously pursue exploratory innovation and exploitative delivery. Policy responsiveness (PR; $\alpha = 0.891$, 7 items) captures the capacity to anticipate regulatory signals and contribute to governance co-evolution. Variable definitions are summarized in Table 1.

Table 1. Variable Definitions and Scale Properties.

Construct	Dimension	Operationalization	Items	α
Leapfrog growth (outcome)	Technology-chain transition (TL)	Transition from customized solutions toward standardized modular architectures proactively integrated by ecosystem partners	7	0.91
Leapfrog growth (outcome)	Value-chain transition (VL)	Shift from project-based fulfillment toward hub-positioning with pricing authority in inter-organizational value networks	4	0.812
Leapfrog growth (outcome)	Institutional-chain transition (IL)	Progression from passive regulatory compliance toward active co-construction of industry standards and governance frameworks	6	0.892
Platform enablement (antecedent)	Rule-based enablement (RE)	Perceived stability of technical standards, interface transparency, and participatory rule-making opportunities provided by the platform	7	0.902
Platform enablement (antecedent)	Business platform enablement (BPE)	Perceived provision of data assets, computation infrastructure, development toolkits, market access, and capital support by the platform	7	0.914
Strategic response capability (antecedent)	Network linkage capability (NLC)	Capacity to orchestrate complementary partners and occupy hub positions in collaboration networks within the platform ecosystem	7	0.905
Strategic response capability (antecedent)	Organizational ambidexterity (OA)	Capacity to simultaneously pursue exploratory innovation and exploitative delivery under platform governance constraints	7	0.895
Strategic response capability (antecedent)	Policy responsiveness (PR)	Capacity to anticipate regulatory signals and proactively contribute to governance co-evolution within the institutional environment	7	0.891

Note: “Leapfrog growth” is a three-dimensional second-order reflective outcome construct; “Platform enablement” and “Strategic response capability” are antecedent condition categories operationalized as five independent fuzzy-set conditions in the fsQCA analysis. Items = number of scale items retained after EFA purification; α = Cronbach’s alpha from the formal survey sample ($N = 374$).

4.3. Research Method: fsQCA

This study employs fuzzy-set Qualitative Comparative Analysis (fsQCA) as its primary analytical method; the comparison with regression-based alternatives offered below is intended solely to clarify the rationale for this methodological choice, not to indicate that multiple methods were applied to the data. Regression-based methods—including multiple regression, structural equation modeling, and hierarchical linear modeling—are well suited to estimating net effects within linear causal chains, answering the question “which variable matters most on average?” under assumptions of linearity and causal symmetry. The research question of this study is different in kind: we ask which combinations of conditions jointly activate leapfrog transitions, rather than which single variable matters most in isolation. As established in Section 2.4, fsQCA is designed precisely for configurational questions of this type, recovering equifinal, asymmetric, and conjunctural causal structures that regression decomposition systematically misrepresents. We therefore select fsQCA not as a substitute for, but as a principled methodological response to, the configurational nature of our theoretical framework.

A legitimate concern regarding the application of fsQCA to large-N survey data is whether perceptual measures are appropriate inputs for set-theoretic configurational analysis. QCA originated in small-N case-comparative research with observable case attributes. We address this concern on three grounds.

First, the focal constructs of this study are inherently socially constructed phenomena. Platform rule engagement, resource absorption, network linkage capability, organizational ambidexterity, and policy responsiveness are defined through the interpretive sense-making of platform participants; they do not have externally observable objective properties. In platform ecosystem research, such constructs are most validly measured through the perceptions of knowledgeable informants who directly engage with platform governance processes, and this has become standard practice in the literature (Ceccagnoli et al., 2012; Ofe & Sandberg, 2022; Cennamo, 2021).

Second, the calibration procedure transforms raw perceptual scores into fuzzy-set membership values using substantive anchors; in our case, the 95th, 50th, and 5th percentiles. This transformation deliberately strips the data of their metric precision and retains only set-membership information, thereby reducing the analytical burden that perceptual accuracy must carry. fsQCA does not ask whether a respondent’s score is precisely correct; it asks only whether the firm is “mostly in,” “crossover,” or “mostly out” of a given condition set.

Third, the large-N application of fsQCA to perceptual survey data is now a well-established methodological practice, adopted in configurational studies published in leading outlets (Fiss, 2011; Greckhamer et al., 2018; Misangyi et al., 2017; Park et al., 2020). Greckhamer et al. (2018) conclude that survey-based large-N fsQCA is appropriate when three conditions are met: the constructs are theoretically configurational in nature, calibration anchors are substantively justified, and results are subjected to sensitivity checks. Our study satisfies all three conditions (see Sections 4.4 and 5.3).

Building on this methodological alignment, we employ fsQCA through specialized computational software (fsQCA 4.1) to examine set-theoretic relationships among antecedent conditions and outcomes (Ragin, 2008; Fiss, 2011). The analysis models causal asymmetry directly: the conditions that prevent technology-chain transition are not the logical negations of the conditions that produce it but constitute an independent causal structure, reflecting the theoretically meaningful reality that firms can fail for reasons entirely unrelated to why other firms succeed. With $N = 374$, the sample provides a more reliable calibration distributional basis than is typical in fsQCA applications, consistent

with Greckhamer et al.'s (2018) recommendation that the method is advantageous for medium-to-large configurational research.

4.4. Calibration

Calibration transforms raw scale scores into fuzzy-set membership values ranging from 0 (full non-membership) to 1 (full membership). For all continuous variables, we applied the direct percentile calibration method (Ragin, 2008): the 95th percentile serves as the full membership anchor (fuzzy score = 0.95), the 50th percentile serves as the crossover point (fuzzy score = 0.50), and the 5th percentile serves as the full non-membership anchor (fuzzy score = 0.05). This approach follows established best practices in fsQCA calibration (Greckhamer et al., 2018) and avoids the arbitrary threshold specification that characterizes alternative calibration approaches. Calibration results are presented in Table 2. Consistency and frequency thresholds for solution acceptance were set at 0.80 (raw consistency), 0.50 (PRI consistency), and frequency ≥ 2 cases per configuration, following Ragin (2008) and Fiss (2011). Notably, in the truth table analyses, the software identified natural break-points above the 0.80 threshold for all three outcome variables—the actual applied cutpoints were 0.862 for technology-chain transition, 0.832 for value-chain transition, and 0.838 for institutional-chain transition—indicating clear empirical discontinuities in the data rather than arbitrary threshold specification.

Table 2. Calibration Results.

Variable	Full Non-Membership (5th)	Crossover (50th)	Full Membership (95th)
Rule enablement (RE)	2.2857	4.5714	6.4286
Business platform enablement (BPE)	2.5714	4.5714	6.4286
Network linkage capability (NLC)	2.2857	4.5714	6.4286
Organizational ambidexterity (OA)	2.7500	4.5000	5.8750
Policy responsiveness (PR)	2.2857	4.5714	6.5714
Technology-chain transition (TL)	2.2500	4.5714	6.4286
Value-chain transition (VL)	2.5000	4.7500	6.5000
Institutional-chain transition (IL)	2.3333	4.6667	6.5000

Note: Calibration values are computed from the formal survey sample ($N = 374$) using the direct method with 95th/50th/5th percentile anchors.

4.5. Temporal Ordering and Causal Direction

Although our cross-sectional design does not permit longitudinal tracking of individual firms, the conditions and outcomes in our model are conceptually situated at different temporal levels, which mitigates—though does not eliminate—concerns about reverse causality. The platform-enablement conditions (RE and BPE) capture the cumulative stock of regulatory and resource provisions that a firm has obtained through its embeddedness in platform ecosystems; such provisions accrue over extended periods of platform engagement and reflect a firm's structural position prior to the focal transformation. In contrast, the three leapfrog outcomes (TL, VL, IL) capture the current flow of transformative changes that the firm is realizing along its technology, value, and institutional chains. This stock–flow distinction implies a logical precedence in which platform-enablement provisions accumulated through prior engagement serve as antecedent conditions for the leapfrog outcomes observed at the time of measurement. We further empirically interrogate this directional assumption through a reverse-causality robustness check reported in Section 5.4.

5. Results

5.1. Necessary Conditions Analysis

Prior to configuration analysis, we assessed whether any single condition constitutes a necessary condition for each outcome. Following QCA methodological protocols (Ragin, 2008; Schneider & Wagemann, 2012), each condition variable (including negated forms) was tested for necessity. A consistency value exceeding 0.90 would identify a condition as necessary, meaning its presence or absence constitutes an indispensable prerequisite for the outcome. Tables 3–5 present the necessary conditions analyses for technology-chain transition, value-chain transition, and institutional-chain transition, respectively.

Table 3. Necessary Conditions Analysis for Technology-Chain Transition (TL).

Conditional Variables	High TL—Consistency	High TL—Coverage	Low TL—Consistency	Low TL—Coverage
High rule enablement	0.709	0.719	0.573	0.551
Low rule enablement	0.557	0.579	0.708	0.698
High business platform enablement	0.676	0.711	0.553	0.551
Low business platform enablement	0.573	0.575	0.710	0.675
High network linkage capability	0.729	0.717	0.554	0.517
Low network linkage capability	0.508	0.546	0.697	0.710
High organizational ambidexterity	0.695	0.710	0.550	0.533
Low organizational ambidexterity	0.543	0.560	0.701	0.686
High policy responsiveness	0.706	0.705	0.578	0.547
Low policy responsiveness	0.546	0.577	0.688	0.689

Table 4. Necessary Conditions Analysis for Value-Chain Transition (VL).

Conditional Variables	High VL—Consistency	High VL—Coverage	Low VL—Consistency	Low VL—Coverage
High rule enablement	0.684	0.699	0.587	0.561
Low rule enablement	0.570	0.596	0.685	0.670
High business platform enablement	0.682	0.722	0.540	0.534
Low business platform enablement	0.560	0.565	0.719	0.679
High network linkage capability	0.703	0.696	0.580	0.537
Low network linkage capability	0.532	0.575	0.672	0.679
High organizational ambidexterity	0.678	0.698	0.569	0.547
Low organizational ambidexterity	0.560	0.581	0.686	0.666
High policy responsiveness	0.682	0.685	0.587	0.552
Low policy responsiveness	0.554	0.589	0.665	0.662

Table 5. Necessary Conditions Analysis for Institutional-Chain Transition (IL).

Conditional Variables	High IL—Consistency	High IL—Coverage	Low IL—Consistency	Low IL—Coverage
High rule enablement	0.704	0.720	0.558	0.532
Low rule enablement	0.542	0.568	0.706	0.690
High business platform enablement	0.689	0.730	0.527	0.521
Low business platform enablement	0.548	0.554	0.727	0.686
High network linkage capability	0.715	0.709	0.565	0.522
Low network linkage capability	0.518	0.561	0.685	0.692
High organizational ambidexterity	0.689	0.710	0.550	0.528
Low organizational ambidexterity	0.542	0.563	0.699	0.677
High policy responsiveness	0.704	0.708	0.563	0.529
Low policy responsiveness	0.532	0.566	0.689	0.685

Note: Conditions with consistency > 0.90 would constitute necessary conditions. None of the tested conditions reached this threshold.

Necessary condition analyses for all three outcome dimensions revealed that no single condition or its negation exhibits a consistency value exceeding the 0.90 threshold (see Tables 3–5). This empirical result confirms that, in China’s autonomous driving platform ecosystem, neither any single dimension of platform enablement nor any single strategic response capability constitutes an individually necessary prerequisite for a leapfrog transition in any chain. The absence of necessary conditions provides strong methodological justification for configurational analysis: leapfrog growth cannot be reduced to ensuring any one condition; it requires specific combinations of conditions working conjointly. This finding aligns with dynamic capabilities theory’s emphasis on the bundle-like nature of capability requirements and challenges any single-factor account of platform-mediated growth.

5.2. Truth Table Analysis

Following Fiss (2011), we distinguish between core and peripheral conditions based on whether a condition appears in both the parsimonious and intermediate solutions (core) or only in the intermediate solution (peripheral). In the present analysis, the parsimonious and intermediate solutions converged for each of the three outcomes, indicating that all conditions retained in the final configurations are core conditions, i.e., each is logically essential to the sufficiency of the configuration and cannot be reduced further through counterfactual simplification. This convergence reflects the tight configurational structure of the three-capability–three-transition framework: given the relatively parsimonious condition set (five antecedents), the truth table does not contain logical remainders whose elimination would differentiate core from peripheral status. We therefore report all retained conditions as core, a practice consistent with prior fsQCA studies reporting converged solutions (Park et al., 2020; Misangyi & Acharya, 2014).

Truth table analysis was conducted separately for each of the three outcome variables using fsQCA 4.1 software. For each analysis, we constructed truth tables based on calibrated fuzzy-set membership scores, applied the specified thresholds (raw consistency ≥ 0.80 , PRI consistency ≥ 0.50 , frequency ≥ 2), and performed Boolean minimization using the Quine-McCluskey algorithm. We report intermediate solutions incorporating theoretical

directional expectations. Importantly, intermediate and parsimonious solutions were identical across all three analyses, meaning all conditions appearing in any pathway are core conditions (●), and no peripheral conditions emerged. Tables 6–8 present high-outcome and low-outcome (non-high) configuration results for technology-chain, value-chain, and institutional-chain transitions, respectively.

Table 6. (a) Configurations for High Technology-Chain Transition (TL). (b) Configurations for Non-High Technology-Chain Transition (TL~).

(a)						
Conditional Variables	TH1	TH2	TH3	TH4	TH5	TH6
Rule enablement (RE)	●	●			●	●
Business platform enablement (BPE)			●	●	●	●
Network linkage cap. (NLC)	●	●	●	●	●	
Org. ambidexterity (OA)	●		●			
Policy responsiveness (PR)		●		●		●
Consistency	0.851	0.857	0.853	0.849	0.842	0.860
Original Coverage	0.515	0.511	0.491	0.493	0.500	0.502
Unique Coverage	0.009	0.007	0.007	0.012	0.020	0.045
Overall Consistency	0.789					
Overall Coverage	0.652					
(b)						
Conditional Variables	NL1	NL2	NL3	NL4	NL5	NL6
Rule enablement (RE)	⊗		⊗			⊗
Business platform enablement (BPE)	⊗	⊗				
Network linkage cap. (NLC)		⊗	⊗	⊗		
Org. ambidexterity (OA)					⊗	⊗
Policy responsiveness (PR)				⊗	⊗	⊗
Consistency	0.732	0.776	0.787	0.761	0.789	0.806
Original Coverage	0.588	0.555	0.542	0.573	0.458	0.475
Unique Coverage	0.082	0.024	0.020	0.048	0.007	0.020
Overall Consistency	0.690					
Overall Coverage	0.816					

(a) Note: ● = core condition present; ⊗ = core condition absent; blank = ‘do not care’ (condition irrelevant). All conditions are core conditions, as intermediate and parsimonious solutions are identical. Overall solution consistency = 0.789; overall solution coverage = 0.652. (b) Note: ⊗ = core condition absent (negated); blank = ‘do not care’. Outcome variable is the negation of technology-chain transition. Overall solution consistency = 0.690; overall solution coverage = 0.816.

Technology-chain transition configurations (Table 6(a,b)). Truth table analysis identified six equifinal pathways to high technology-chain transition and six pathways associated with non-high transition (Table 6(a,b)). The high-outcome configurations reveal two dominant pathway families.

Network linkage-led pathways (TH1–TH5) feature network linkage capability (NLC) as the modal core condition, present in five of six configurations, underscoring its centrality beyond what the original theory predicted. Platform enablement (either RE or BPE) appears in all six pathways, establishing it as the foundational prerequisite for technology-chain transition. Within this family, TH1 (RE + NLC + OA) and TH3 (BPE + NLC + OA) reflect an

‘institutional innovation’ mechanism: rule- or resource-based platform enablement, combined with network linkage and organizational ambidexterity, jointly produce standardized modular architectures. TH2 (RE + NLC + PR) and TH4 (BPE + NLC + PR) substitute organizational ambidexterity with policy responsiveness, reflecting a ‘standards-participation’ mechanism where regulatory engagement accelerates technology standardization. TH5 (RE + BPE + NLC) demonstrates that dual-platform enablement combined with network linkage suffices without additional capability specification, suggesting a ‘resource-amplified coordination’ mechanism.

Table 7. (a) Configurations for High Value-Chain Transition (VL). (b) Configurations for Non-High Value-Chain Transition (VL~).

(a)				
Conditional Variables	VH1	VH2	VH3	VH4
Rule enablement (RE)	●	●		●
Business platform enablement (BPE)	●		●	●
Network linkage cap. (NLC)		●	●	●
Org. ambidexterity (OA)		●	●	●
Policy responsiveness (PR)	●	●	●	
Consistency	0.819	0.818	0.830	0.838
Original Coverage	0.475	0.450	0.436	0.436
Unique Coverage	0.064	0.039	0.026	0.026
Overall Consistency	0.778			
Overall Coverage	0.566			
(b)				
Conditional Variables	NL1	NL2	NL3	NL4
Rule enablement (RE)	⊗		⊗	
Business platform enablement (BPE)	⊗	⊗		⊗
Network linkage cap. (NLC)				
Org. ambidexterity (OA)				⊗
Policy responsive. (PR)		⊗	⊗	
Consistency	0.733	0.743	0.739	0.769
Orig. Coverage	0.593	0.533	0.520	0.550
Unique Coverage	0.048	0.007	0.001	0.005
Overall Consistency	0.641			
Overall Coverage	0.827			

(a) Note: ● = core condition present; blank = ‘do not care’. All conditions are core. Overall solution consistency = 0.778; overall solution coverage = 0.566. (b) Note: ⊗ = core condition absent (negated); blank = ‘do not care’. Outcome variable is the negation of value-chain transition. Overall solution consistency = 0.641; overall solution coverage = 0.827.

Policy responsiveness-led pathway (TH6) is the only configuration excluding network linkage capability, pairing dual-platform enablement with policy responsiveness alone. Notably, TH6 has the highest unique coverage (0.045), explaining cases that no other pathway covers. This suggests a distinct ‘institution-driven technology’ pathway in which firms convert policy signals into technical compliance actions, progressively accumulating standards-participation credentials through regulatory engagement rather than network coordination.

Table 8. (a) Configurations for High Institutional-Chain Transition (IL). (b) Configurations for Non-High Institutional-Chain Transition (IL~).

(a)				
Conditional Variables	IH1	IH2	IH3	IH4
Rule enablement (RE)	●	●	●	
Business platform enablement (BPE)	●	●		●
Network linkage cap. (NLC)	●		●	●
Org. ambidexterity (OA)			●	●
Policy responsiveness (PR)		●	●	●
Consistency	0.848	0.855	0.866	0.866
Original Coverage	0.500	0.495	0.475	0.454
Unique Coverage	0.049	0.044	0.047	0.026
Overall Consistency	0.807			
Overall Coverage	0.618			
(b)				
Conditional Variables	NL1	NL2	NL3	NL4
Rule enablement (RE)	⊗		⊗	
Business platform enablement (BPE)	⊗	⊗		⊗
Network linkage cap. (NLC)				
Org. ambidexterity (OA)				⊗
Policy responsive. (PR)		⊗	⊗	
Consistency	0.736	0.767	0.760	0.770
Orig. Coverage	0.597	0.551	0.536	0.552
Unique Coverage	0.056	0.004	0.002	0.007
Overall Consistency	0.673			
Overall Coverage	0.842			

(a) Note: ● = core condition present; blank = ‘do not care’. All conditions are core. Overall solution consistency = 0.807; overall solution coverage = 0.618. This is the highest solution consistency across all three outcome dimensions. (b) Note: ⊗ = core condition absent (negated); blank = ‘do not care’. Outcome variable is the negation of institutional-chain transition. Overall solution consistency = 0.673; overall solution coverage = 0.842.

The non-high-technology-chain configurations reinforce an asymmetric causal logic. NL1 (absence of both RE and BPE) has the highest unique coverage (0.082), demonstrating that comprehensive platform enablement deficiency is the single most independently explanatory condition for technology-chain failure. NL4 (absent NLC + absent PR) and NL2 (absent BPE + absent NLC) follow in explanatory importance, confirming that network-related deficiencies constitute a secondary failure pathway. Critically, the non-high pathways are not logical mirrors of the high pathways: the absence of network linkage capability is not universally present in low-transition configurations (NL1 does not include ~NLC), meaning platform enablement deficiency alone is sufficient to prevent technology-chain leapfrogging regardless of network capability levels.

Value-chain transition configurations (Table 7(a,b)). Four equifinal pathways to high value-chain transition were identified (Table 7(a)), achieving overall consistency of 0.778 and coverage of 0.566. Contrary to the framework’s initial prediction that business platform enablement and network linkage capability would be the primary configuration, the results reveal that policy responsiveness (PR) emerges as the modal core condition, present in

three of four high-VL configurations. Configuration VH1 (RE + BPE + PR) achieves the highest unique coverage (0.064), representing a ‘dual-enablement policy leverage’ pathway: firms with strong policy responsiveness capitalize on both rule-based and resource-based platform enablement to access institutionalized commercial channels—demonstration area operating licenses, government procurement priority, and provincial pilot funding—that reduce commercial friction costs and directly accelerate the transition from hardware delivery to service-based revenue models. This finding reflects the distinctive institutional context of China’s autonomous driving market, where policy responsiveness provides preferential access to commercially validated scenarios that platform resources and rules alone cannot guarantee.

Configurations VH2 (RE + NLC + OA + PR), VH3 (BPE + NLC + OA + PR), and VH4 (RE + BPE + NLC + OA) represent comprehensive capability-coordination pathways. VH2 and VH3 demonstrate that policy responsiveness can be combined with network linkage capability and organizational ambidexterity under either rule-based or business platform enablement to achieve value-chain transitions. VH4, which substitutes policy responsiveness with dual-platform enablement, reveals that resource richness combined with network linkage and ambidexterity constitutes an alternative pathway for value-chain leapfrogging when policy advantage is unavailable. The nine non-high value-chain configurations (Table 7(b)) confirm this pattern’s asymmetry: NL1 ($\sim$ RE + $\sim$ BPE, unique coverage 0.048) retains the highest independent explanatory power for value-chain failure, while the multiplicity of pathways (nine configurations explaining 82.7% of cases) reflects the inherently complex and multi-factorial nature of value-chain stagnation.

Institutional-chain transition configurations (Table 8(a,b)). Institutional-chain transition exhibits the highest solution quality of the three outcome dimensions (overall consistency = 0.807, exceeding the 0.80 ideal threshold), with four equifinal pathways identified (Table 8(a)). Two parallel pathway families emerge. The first family encompasses.

Dual-enablement pathways in which both RE and BPE are simultaneously present: IH1 (RE + BPE + NLC) is a network-linkage-anchored dual-enablement pathway, in which firms with strong network linkage capability operate under joint rule-based and resource-based platform provisions. The interpretive significance of this configuration is discussed in Section 6.3.; IH2 (RE + BPE + PR) represents an ‘individual compliance-upgrading’ mechanism: firms translate regulatory signals into proactive compliance proposals and directly participate in rule-making. The near-equal unique coverages of IH1 (0.049) and IH2 (0.044) provide empirical evidence of genuine equifinality: institutional-chain leapfrogging is achievable through two qualitatively distinct mechanisms, with collective network mobilization and individual policy engagement constituting interchangeable routes when dual-platform enablement is in place. The second family encompasses.

Full-capability pathways requiring only single-dimensional platform enablement: IH3 (RE + NLC + OA + PR) and IH4 (BPE + NLC + OA + PR) demonstrate that firms with all three strategic response capabilities can achieve institutional-chain transitions supported by either rule-based or business platform enablement alone. This reveals a ‘comprehensive capability substitution effect’: when firms possess the full portfolio of strategic response capabilities, they can compensate for the absence of one enablement dimension with the depth of their organizational and relational capabilities.

The eight non-high institutional-chain configurations (Table 8(b)) reveal two distinct failure pathways with high independent explanatory power. NL1 ($\sim$ RE + $\sim$ BPE, unique coverage 0.056) confirms, consistent with the other two chains, that comprehensive platform enablement absence is the single most explanatory condition for institutional-chain failure. NL8 ($\sim$ NLC + $\sim$ PR, unique coverage 0.044) reveals a second independent failure mode absent in the other chains: the simultaneous absence of network linkage capabil-

ity and policy responsiveness—the two capabilities most directly linked to institutional participation—constitutes a distinct failure pathway for institutional leapfrogging. This finding underscores the dual institutional competence requirement for institutional-chain transitions: neither collective mobilization capacity nor individual policy navigation capacity can be entirely substituted in the institutional domain. Table 9 presents representative cases of each fully configured type.

Table 9. Representative Cases for Each Sufficient Configuration.

Pathway	Configuration	Representative Case	Brief Empirical Grounding
TH2	NLC·PR·RE	RoboSense	Engaged Baidu Apollo’s interface certification standards while maintaining parallel R&D tracks for Apollo and Mercedes-Benz architectures.
TH6	PR·RE·BPE	Momenta	Leveraged its “two-flywheel” strategy to amass over 60% market share in urban NOA through deep OEM partnerships, including a \$1 billion investment from SAIC and collaboration with Mercedes-Benz, while maintaining policy responsiveness across Chinese and international regulatory frameworks.
VH1	PR·RE·BPE	Neolix	Leveraged Apollo’s annotated urban delivery datasets and policy responsiveness to position itself within the autonomous logistics regulatory framework.
VH2/3/4	NLC·OA·PR (+RE/BPE)	Hesai Technology	As the global leader in automotive LiDAR with 33% market share, Hesai achieved quarterly profitability in 2025 through its ATX LiDAR platform, penetrating the 100,000 RMB vehicle segment, coupled with “chip-level cost reduction and scaled delivery,” demonstrating network linkage capabilities across OEMs and dual-use adaptability in automotive and robotics markets.
IH1	NLC·RE·BPE	Horizon Robotics	Through deep engagement with Apollo’s chipset integration standards via Journey series, mobilized inter-organizational consortia for national demonstration projects, while maintaining 45.8% market share in China’s basic ADAS solutions segment.
IH2	PR·RE·BPE	Yoka Technology	Deeply integrated with Baidu Apollo through a “technology + market” strategic alliance to deliver integrated hardware-software telematics solutions for Robotaxi operations, expanding from connectivity management to full-stack “vehicle-road-cloud” ecosystem co-construction while navigating evolving autonomous driving regulatory frameworks.

Note: Representative cases were selected based on the highest joint membership scores in the configuration and the corresponding outcome dimension. Brief empirical descriptions draw on case-based field knowledge to anchor the configurational patterns identified in this section.

5.3. Robustness Tests

We conducted a series of robustness checks to validate the stability of configurational solutions, following Fiss (2011) and Zhang and Du (2019): a common method bias assessment, an adjusted consistency threshold test, an alternative calibration test, and a reverse-causality test (Section 5.4).

Test 0: Common Method Bias Assessment. Because all core constructs were measured through a single self-report questionnaire administered to a single key informant per

firm, we assessed the potential for common method bias (CMB) following Podsakoff et al. (2003) and Chang et al. (2010). Procedurally, the questionnaire was designed with temporal separation between condition and outcome items, anonymous response protocols, neutrally framed item wording, and reverse-scored items to reduce consistency motif and social desirability effects. Statistically, we performed Harman's single-factor test by entering all 64 observed indicators—reverse-coded items having been recoded prior to analysis—into an unrotated principal component analysis in SPSS 26.0. The sampling adequacy of the data was first confirmed: the Kaiser–Meyer–Olkin measure was 0.939, and Bartlett's test of sphericity was significant (approximate $\chi^2 = 16126.635$, $df = 2016$, $p < 0.001$), indicating that the data were well suited for factor analysis. The unrotated solution extracted eleven factors with eigenvalues greater than one, jointly explaining 69.527% of the total variance. The first extracted factor accounted for 27.721% of the variance, well below the 40% threshold recommended by Podsakoff et al. (2003) and substantially below the more lenient 50% benchmark; no single factor dominated the variance structure. These results indicate that common method bias is unlikely to materially distort the configurational results reported in this study. We additionally note that fsQCA is inherently less vulnerable to common method bias than covariance-based methods, as it analyzes set-theoretic relationships among calibrated fuzzy-set membership scores rather than variance–covariance structures among raw indicators (Greckhamer et al., 2018); the calibration procedure itself discards metric precision and retains only information about set membership, further attenuating the impact of any residual common-method variance.

Test 1: Adjusted raw consistency threshold ($0.80 \rightarrow 0.85$). We increased the raw consistency threshold from 0.80 to 0.85 while maintaining the original frequency threshold (≥ 2) and PRI consistency threshold (0.50). This modification yielded completely unchanged solution results for all three outcome configurations. The invariance arises because the truth tables contain clear natural breakpoints: no configuration's consistency value falls between 0.800 and 0.862 (Y_1), between 0.800 and 0.832 (Y_2), or between 0.800 and 0.838 (Y_3). The threshold adjustment, therefore, includes and excludes exactly the same configurations as the original analysis, confirming that the solution structure reflects objective data discontinuities rather than arbitrary parameterization.

Test 2: Adjusted calibration anchors ($P95/P50/P5 \rightarrow P90/P50/P10$). We replaced the original calibration anchors with the 90th/50th/10th percentile thresholds for all eight variables, generating an alternative calibration dataset (denoted with _rob suffix), and reran all analyses under identical frequency and consistency parameters. Results demonstrate strong robustness: necessary conditions analyses continued to show no condition exceeding the 0.90 threshold (highest value: SRC_NC for all three chains, ranging from 0.684 to 0.710); platform enablement conditions (RE, BPE) retained core roles across all outcome configurations; and the chain-specific dominance of NLC for TL, PR for VL, and dual-enablement for IL configurations was preserved. Overall solution consistency values remained within acceptable ranges (Y_1 : 0.766; Y_2 : 0.764; Y_3 : 0.803), all above Ragin's (2008) 0.750 minimum. For value-chain transition under alternative calibration, one additional configuration emerged containing negated conditions (absent RE, absent OA), with a raw coverage of 0.196, suggesting that in specific resource-rich, rule-light environments, network linkage capability may drive value-chain transition through a resource-substitution mechanism. This supplementary pathway does not alter the core finding that policy responsiveness constitutes the primary value-chain transition pathway; it warrants attention in future research as a boundary condition.

5.4. Robustness Check: Testing for Reverse Causality

A common concern in cross-sectional configurational research is reverse causality; specifically, whether firms that have already achieved leapfrog growth are more likely to attract platform-enablement provisions, rather than the reverse. To interrogate this concern, we re-estimated the fsQCA model with the causal direction reversed: the three leapfrog dimensions (TL, VL, IL) were specified as conditions, while the two platform-enablement dimensions (RE and BPE) were specified as outcomes. All calibration anchors and analytical thresholds were held identical to those of the forward model to ensure comparability.

Necessity analysis. As reported in Table 10, none of the three leapfrog dimensions reaches the conventional necessity threshold of 0.90 for either platform-enablement outcome: consistency values range from 0.865 to 0.876 for RE and from 0.865 to 0.884 for BPE. This indicates that leapfrog status is not a necessary condition for platform enablement: firms can obtain platform-enablement provisions without first having undergone leapfrog transformation along any specific chain. It is worth noting that these reverse-direction necessity values are higher than those observed for individual conditions in the forward model (where consistency values for the five enablement and capability conditions range between 0.508 and 0.729 across TL, VL, and IL outcomes; see Tables 3–5). This elevation reflects a baseline covariation pattern: firms with high leapfrog performance also tend to exhibit high platform-enablement scores, rather than evidence of a reverse causal mechanism. Disentangling covariation from causal direction requires examination of the configurational sufficiency structure.

Table 10. Necessity Analysis under Reverse Specification.

Condition	Outcome: RE		Outcome: BPE	
	Consistency	Coverage	Consistency	Coverage
TL	0.867	0.865	0.865	0.861
~TL	—	1.000	—	1.000
VL	0.876	0.844	0.884	0.850
~VL	—	1.000	—	1.000
IL	0.874	0.854	0.878	0.855
~IL	—	1.000	—	1.000

Note: Necessity threshold is conventionally set at 0.90. None of the three leapfrog conditions exceeds this threshold for either outcome.

Sufficiency analysis. The sufficiency results (Table 11) yield a more telling pattern. Whereas the forward model produced multiple equifinal configurations for each leapfrog outcome (six pathways for TL, four for VL, and four for IL), with solution coverage ranging from 0.566 to 0.652, the reverse model converges on a single degenerate configuration—TL*VL*IL—for both RE (raw coverage = 0.443, consistency = 0.999) and BPE (raw coverage = 0.444, consistency = 0.999). In other words, the reverse model can only “explain” platform enablement under the trivial condition that a firm scores high on all three leapfrog dimensions simultaneously, and it generates no alternative configurational pathways. The unusually high consistency value in the reverse model is an artifact of this degenerate solution structure—only the most restrictive intersection of conditions survives the truth-table reduction—rather than evidence of stronger causal force. The substantively meaningful comparison lies in solution coverage and configurational diversity, both of which strongly favor the forward model.

Table 11. Comparison of Forward and Reverse Sufficiency Models.

Model	Outcome	# of Configurations	Solution Coverage	Solution Consistency
Forward	TL	6	0.652	0.789
Forward	VL	4	0.566	0.778
Forward	IL	4	0.618	0.807
Reverse	RE	1	0.443	0.999
Reverse	BPE	1	0.444	0.999

Note: The forward model exhibits multiple equifinal pathways with substantial joint coverage (0.566–0.652), whereas the reverse model converges on a single degenerate configuration (TL*VL*IL) with markedly lower coverage (0.443–0.444) and no equifinality. The unusually high consistency in the reverse model is an artifact of the degenerate solution structure, in which only the most restrictive intersection of conditions is retained, rather than evidence of a stronger causal force. The asymmetric configurational structure between the two directions supports the theoretically posited causal direction from platform enablement to leapfrog growth.

Taken together, the necessity and sufficiency evidence does not merely mitigate reverse-causality concerns: it empirically falsifies the reverse specification as a viable alternative explanation for the observed patterns. The reverse model’s inability to generate more than a single degenerate configuration, despite operating on identical calibration anchors and thresholds, indicates that the configurational structure of our data is directionally committed: platform enablement configurations produce leapfrog outcomes, not the reverse. While cross-sectional designs preclude strict causal identification in the experimental sense, the asymmetry in configurational structure between forward and reverse specifications provides the strongest evidence of directionality available within a set-theoretic analytical framework.

6. Discussion

Building on the configurational patterns identified in Section 5.2, we propose three interpretive mechanisms, one for each leapfrog dimension. These mechanisms account for the empirical regularities observed across the sufficient configurations. They are advanced as theoretically grounded interpretations rather than directly tested causal claims, and they warrant further empirical and theoretical scrutiny in future research. The case illustrations included in the following subsections are drawn from in-depth field knowledge of representative firms in China’s autonomous driving ecosystem. They are intended to anchor, not to verify, the proposed mechanisms.

6.1. Theoretical and Empirical Distinctiveness of the Three Leapfrog Dimensions

We first address a foundational question that any multi-outcome framework must answer. Are the three leapfrog dimensions genuinely distinct constructs, or are they alternative manifestations of a single underlying growth phenomenon? We argue, on both conceptual and configurational grounds, that the three dimensions are non-reducible.

Conceptual distinction. The three leapfrog dimensions are theoretically anchored at different analytical levels of the firm and capture qualitatively different transformation processes. As summarized in Table 12, TL operates at the technology-architecture level. The unit of change is the firm’s underlying technical capability stack, and the observable signal is a discontinuous reconfiguration of core technologies, patents, or product architectures. VL operates at the value-network level. The unit of change is the firm’s position in the inter-organizational value flow, and the observable signal is a restructuring of customer composition, profit pools, or upstream–downstream relationships. IL operates at the institutional-environment level. The unit of change is the firm’s relational status vis-à-vis rule-makers and standard-setters, and the observable signal is participation in standard formulation, acquisition of regulatory legitimacy, or shifts in policy identity. These three

dimensions correspond to distinct loci of change: technical, relational, and institutional. A firm can therefore leapfrog along one chain without simultaneously leapfrogging along the others, and the mechanisms enabling each type of leapfrog need not be identical.

Table 12. Conceptual Distinctions among the Three Leapfrog Dimensions.

Dimension	Locus of Change	Mechanism of Transformation	Observable Signal
TL (Technology-Chain)	Technology architecture	Capability reconstruction	Patent reconfiguration; architectural migration
VL (Value-Chain)	Inter-organizational value network	Value redistribution	Customer-base shift; profit-pool migration
IL (Institutional-Chain)	Institutional environment	Rule reconstruction	Standards participation; regulatory status; policy identity

Configurational distinction. If TL, VL, and IL were merely different manifestations of a single latent construct, the fsQCA solutions for the three outcomes would be expected to converge on substantially overlapping configurations. Our results show the opposite. The three outcomes yield configurational structures that differ systematically along three observable dimensions.

First, the number of equifinal pathways differs across outcomes. TL is reached through six distinct configurations, while VL and IL are each supported by four. The greater pathway diversity for TL suggests that technology-chain leapfrogging can be triggered through more varied combinations of platform enablement and firm capability. Value- and institutional-chain leapfrogging, by contrast, require more selective combinations.

Second, the dominant capability conditions differ across outcomes. Network linkage capability (NLC) appears as a core condition in five of the six TL pathways. TL is therefore primarily a network-driven outcome. By contrast, all four VL pathways require the joint presence of at least two of the three firm-capability conditions (NLC, organizational ambidexterity, and policy responsiveness). VL is thus a capability-intensive outcome that demands multiple internal competences in concert. IL, in turn, exhibits the strongest dependence on policy responsiveness (PR). PR appears as a core condition in three of the four IL pathways and constitutes the sole capability anchor of one parsimonious IL configuration (PR*RE*BPE). The differential prominence of NLC, joint-capability bundles, and PR across the three outcomes points to qualitatively different enabling mechanisms rather than a shared underlying driver.

Third, no configuration is shared identically across the three outcomes. Surface similarities do appear; for example, a PR-anchored configuration surfaces in both VL and IL solutions. Yet the unique coverage values and accompanying conditions differ, and the same configuration carries different explanatory weight within each outcome's solution. The reverse-causality robustness check reported in Section 5.4 reinforces this point. The only configuration capable of "explaining" platform enablement under reverse specification is the trivial intersection TL*VL*IL. This intersection is itself an artifact of treating the three dimensions as separable conditions.

Taken together, these conceptual and configurational arguments indicate that TL, VL, and IL are not interchangeable indicators of a single growth construct. They capture distinct, complementary facets of leapfrog transformation. We therefore proceed to interpret the three sets of configurations as evidence of three distinct but related enabling mechanisms.

6.2. Technology-Chain Transition Configurations

The technology-chain configurations reveal a mechanism that substantially revises the original theoretical expectation. Network linkage capability (NLC), rather than organizational ambidexterity, anchors technology-chain leapfrogging. This points to an inherently inter-organizational rather than intra-organizational process.

Configuration TH1 combines rule enablement, network linkage capability, and organizational ambidexterity. It embodies a “coordinated standardization” mechanism. Platform governance clarity (RE) provides the institutional framework for technical development. Inter-organizational network coordination (NLC) enables cross-partner validation and module diffusion. Organizational ambidexterity (OA) manages the internal exploration-exploitation balance required to deliver compliant products while simultaneously pursuing architectural innovation. This triple combination produces the technology-chain leader’s defining output: architectures that are simultaneously platform-compliant, inter-partner validated, and technically generative.

The case of RoboSense exemplifies this configurational logic. RoboSense engaged deeply with Baidu Apollo’s interface certification standards (rule enablement). It maintained parallel R&D tracks for platform-compliant sensor modules (exploitation) and next-generation solid-state architectures (exploration). Through this dual engagement, RoboSense achieved a technology-chain transition from a peripheral sensor supplier to an ecosystem reference standard provider. Its MEMS solid-state radar became the de facto benchmark for mid-range autonomous driving perception and was integrated across multiple platform ecosystems simultaneously. Critically, this transition was enabled not despite but through the discipline imposed by platform governance. The need to achieve Apollo certification forced architectural standardization that subsequently enabled replication across other platforms. The case demonstrates how rule-based enablement and organizational ambidexterity jointly produce the standardized yet innovative architectures that characterize technology-chain leaders.

The managerial insight for practicing executives is concrete. Consider a complementor firm with a limited capability-building budget, deciding between hiring five additional R&D engineers or seconding three senior staff to Apollo’s partner technical committees. Our findings suggest that the second option is more likely to produce technology-chain leapfrogging in the studied context. Technology-chain leapfrogging is fundamentally an inter-organizational achievement, not an internal capability accumulation process. Firms that over-invest in internal R&D without building the external network access needed to translate R&D into recognized standards risk stalling at the peripheral level despite their technical competence. Concrete capability-investment guidance is developed in Section 7.2.

Proposition 4. *Technology-chain leapfrog transition is achieved when platform enablement (rule-based or resource-based) combines with network linkage capability as the modal enabling mechanism, with organizational ambidexterity serving as an amplifying condition. Network linkage capability provides the inter-organizational coordination that is a necessary structural complement to platform governance inputs. Technology standardization and modular replication are inherently multi-actor achievements and cannot be accomplished through internal organizational mechanisms alone.*

6.3. Value-Chain Transition Configurations

Value-chain transition configurations reveal a finding that departs significantly from the initial theoretical prediction. Policy responsiveness (PR) emerges as the modal core condition. It appears in three of four high-VL configurations and anchors the pathway with the highest unique coverage (VH1, unique coverage = 0.064). This pattern reflects a

distinctive institutional mechanism in China's autonomous driving market that cannot be captured by resource-centric or network-centric theories alone.

Configuration VH1 combines rule-based and resource-based platform enablement with policy responsiveness. It represents what we term the "institutional leverage" pathway. Firms with strong policy responsiveness capability gain preferential access to demonstration area operating licenses, government procurement priority, and provincial pilot funding. These institutionally conferred advantages lower the friction costs of multi-party ecosystem coordination more effectively than direct networking efforts. They enable rapid transitions from hardware delivery to service-based revenue models. Crucially, institutional endorsement partially substitutes for network linkage capability. The government-certified operational status that policy-responsive firms obtain signals trustworthiness to potential commercial partners, bypassing the relational investment that network-building would otherwise require (Scott, 1995).

Neolix's value-chain trajectory illustrates this pathway. Neolix leveraged Baidu Apollo's annotated urban delivery scenario dataset (business platform enablement) to accelerate its perception algorithm development. Simultaneously, it built partnerships with JD Logistics, Meituan, and Suning across three distinct application domains (network linkage capability). This multi-partner ecosystem positioning enabled Neolix to transition from a hardware supplier accepting project-based orders to an ecosystem integrator with revenue-sharing agreements, licensing arrangements, and co-development contracts across verticals. The transition was enabled by the resource base Apollo provided. Without the annotated dataset, algorithm development would have required proprietary data acquisition investment that would have precluded simultaneous network expansion. The transition was then actualized through the networking capability that converted resource advantages into hub-level value appropriation.

The managerial insight carries direct implications for resource sequencing. Consider a complementor firm that has recently joined Apollo's ecosystem and must choose whether to invest first in a dedicated business development team to expand customer relationships or in a dedicated regulatory affairs team to track and respond to provincial pilot-program opportunities. In the studied context, the second choice more frequently unlocks value-chain leapfrogging, because policy-responsiveness credentials provide the institutional legitimacy that then makes subsequent commercial partnerships substantially easier to form. Value-chain leapfrogging in this ecosystem is primarily institutionally mediated rather than resource- or network-mediated in isolation, which means that capability-investment choices must be sequenced around policy-responsiveness foundations rather than customer-relationship foundations. Specific guidance follows in Section 7.2.

Proposition 5. *In institutionally embedded platform ecosystems, value-chain leapfrog transition is primarily achieved through policy responsiveness capability leveraging dual-platform enablement. Institutionally conferred advantages (operating licenses, procurement priority, pilot funding) reduce commercial coordination costs and accelerate business model transitions. Firms lacking policy responsiveness access can substitute comprehensive capability coordination (network linkage combined with organizational ambidexterity) as an alternative but more resource-intensive pathway.*

6.4. Institutional-Chain Transition Configurations

The central finding for institutional-chain transition is genuine equifinality between two mechanistically distinct pathways, both anchored in dual-platform enablement. Configuration IH1 (RE + BPE + NLC) and Configuration IH2 (RE + BPE + PR) exhibit virtually identical unique coverages (0.049 vs. 0.044). Network linkage capability and policy responsiveness capability are therefore functionally substitutable for institutional-chain transition when dual-platform enablement is in place. This equifinality is the analytically most

significant finding in the institutional-chain analysis, and one that regression analysis cannot detect.

IH1 represents a “collective institutional entrepreneurship” pathway. Firms with strong network linkage capability mobilize multi-party collaborative networks. They co-sponsor national demonstration projects, aggregate industry-level operational data, and jointly author technical white papers. Through these actions, they convert distributed industry practices into legitimate collective institutional discourse. The platform’s dual enablement provides the regulatory credibility (RE) and empirical data resources (BPE) that underpin this collective standard-setting action. IH2, by contrast, represents an “individual compliance-upgrading” pathway. Firms with strong policy responsiveness decode regulatory signals proactively, translate them into technical compliance roadmaps, and submit evidence-based policy recommendations. These actions position them as authoritative individual contributors to rule-making. The equifinality between these two pathways carries a crucial practical implication: institutional-chain leapfrogging does not require a single optimal configuration. Firms can select the pathway aligned with their relational assets (choose IH1 if network-rich) or with their institutional intelligence (choose IH2 if policy-responsive).

Horizon Robotics’ institutional-chain transition illustrates this dual institutional logic. Horizon engaged deeply with Baidu Apollo’s chipset integration standards (rule enablement) by developing its Journey series processors to Apollo’s computational architecture specifications. This engagement gave Horizon the technical credibility and ecosystem embeddedness that positioned it as an authoritative voice in autonomous computing standard discussions. Simultaneously, Horizon exercised systematic policy responsiveness. It anticipated the Ministry of Industry and Information Technology’s vehicle computing platform standardization initiatives and pre-emptively aligned its product roadmap with draft standards. As a result, Horizon co-authored multiple national automotive computing platform standards. The institutional-chain transition from chip supplier to national standard contributor was contingent on both dimensions simultaneously. Rule-enablement-based ecosystem credibility provided the technical authority, while policy responsiveness provided the regulatory access pathway.

The managerial insight is liberating rather than prescriptive. Consider two complementary firms with identical ambitions to become national standard contributors: one has a strong technical advisory board with cross-industry connections, while the other has an experienced former government official leading its policy team. The equifinality finding implies that neither firm needs to build what it lacks. The first should pursue the collective institutional entrepreneurship pathway (IH1), leveraging its network assets to mobilize industry consortia. The second should pursue the individual compliance-upgrading pathway (IH2), leveraging its policy intelligence to co-author regulations. Both routes lead to the same institutional-chain leapfrog outcome, provided dual-platform enablement is in place. This is a substantially more permissive strategic implication than conventional capability-building prescriptions suggest, and it directly addresses the resource-constraint reality facing most complementor firms. Specific implementation guidance is provided in Section 7.2.

Proposition 6. *Institutional-chain leapfrog transition requires dual-platform enablement as the foundational structural condition. Network linkage capability and policy responsiveness capability constitute equifinal strategic response mechanisms. Collective institutional entrepreneurship (NLC-anchored) and individual compliance upgrading (PR-anchored) represent functionally equivalent but mechanistically distinct routes to standard co-construction. The choice between them is contingent on firms’ relational positioning and institutional intelligence endowments.*

6.5. Cross-Chain Comparison and Theoretical Integration

Following the chain-specific discussions in Sections 6.2–6.4, this section synthesizes cross-chain findings to identify regularities and divergences that span all three leapfrog dimensions. Table 13 summarizes the comparative importance of each antecedent condition across the three chains. These importance ratings are derived from each condition's frequency of appearance and unique coverage contribution across all 14 high-outcome configurations.

Table 13. Comparative Importance of Antecedent Conditions Across Three Leapfrog Chains.

Chain Dimension	RE	BPE	NLC	OA	PR	Dominant Configuration Logic
TL (Technology)	★★★	★★★	★★★★★	★★	★★	NLC + platform enablement dominant; PR-only as alternative PR as primary path; comprehensive capability coordination as secondary Dual enablement as foundation; NLC and PR as equifinal alternatives
VL (Value)	★★★	★★★	★★★	★★★★	★★★★★	
IL (Institutional)	★★★★★	★★★	★★★	★★	★★★★	

Note: ★★★★★ = very high importance; ★★★ = high importance; ★★ = moderate importance. Importance ratings are based on condition frequency in intermediate solution pathways and unique coverage contributions. RE = rule enablement; BPE = business platform enablement; NLC = network linkage capability; OA = organizational ambidexterity; PR = policy responsiveness.

Finding 1: Platform enablement is the universal structural prerequisite. The most consistent cross-chain pattern is the universal presence of platform enablement across all 14 high-outcome configurations. No single pathway achieves a leapfrog transition in any chain while both rule enablement (RE) and Business platform enablement (BPE) are simultaneously absent. This finding provides configurational-level validation of the framework's core theoretical premise: platform enablement is a necessary structural condition for leapfrog growth among autonomous driving complementary firms. The non-high outcome analyses corroborate this from the opposite direction. The joint absence of RE and BPE (~RE~BPE) consistently generates the highest unique coverage in non-high configurations across all three chains (0.082 for technology-chain, 0.048 for value-chain, and 0.056 for institutional-chain). Comprehensive platform enablement deficiency is therefore the single most independently explanatory condition for leapfrog failure across all dimensions. Platform enablement is not, however, a sufficient condition for leapfrog growth in any chain. Every high-outcome configuration requires the co-presence of at least one strategic response capability.

Finding 2: Chain-specificity of strategic response capabilities. The three strategic response capabilities (NLC, OA, PR) do not exert uniform influence across the three leapfrog dimensions. Instead, each capability exhibits strong chain-specificity (Table 13). Network linkage capability (NLC) is the modal core condition for technology-chain transition, appearing in five of six high-TL configurations. This result substantially exceeds the original theoretical prediction that organizational ambidexterity (OA) would be the primary TL-enabling capability. The empirical revision reveals that technology standardization and modular architecture replication in platform ecosystems are inherently inter-organizational achievements. Firms cannot achieve standards-setting authority through internal organizational mechanisms alone. They must mobilize collaborative networks of platform partners, OEM integrators, and scenario operators to validate and propagate their technical architectures.

Policy responsiveness (PR) emerges as the modal core condition for value-chain transition. It appears in three of four high-VL configurations with the highest unique coverage (0.064), again departing from the initial theoretical prediction that business platform enablement and network linkage would constitute the primary VL pathway. This finding reflects the distinctive institutional context of China's autonomous driving market. Policy responsiveness confers preferential access to demonstration area operating licenses, government procurement priority, and provincial pilot funding. These institutionally mediated commercial advantages directly lower the friction costs of multi-party ecosystem coordination and accelerate business model transitions from hardware delivery toward service-based revenue models. The Chinese state's active industrial governance apparatus thus functions as a *de facto* accelerator for value-chain leapfrogging.

For institutional-chain transition, chain-specificity takes the form of equifinality between two qualitatively distinct pathways: network linkage (IH1) and policy responsiveness (IH2). Both are anchored in dual-platform enablement and exhibit nearly identical unique coverages (0.049 vs. 0.044). Organizational ambidexterity (OA) demonstrates the weakest chain-specificity. It functions primarily as a supporting condition in comprehensive capability coordination pathways (VH2, VH3, VH4, IH3, IH4), not as a modal core condition in any chain. This pattern suggests that OA serves as a capacity amplifier. When present alongside more chain-specific capabilities, it extends the operational range of those capabilities rather than acting as an independent driver of any particular leapfrog dimension.

Finding 3: Asymmetric causal logic. The systematic comparison of high-outcome and non-high-outcome configurations reveals structural asymmetry between success and failure pathways. High-outcome pathways consist exclusively of condition presence (●), while non-high pathways are dominated by condition absences (⊗). Growth is therefore activated by presence configurations, whereas stagnation is produced by absence configurations. Moreover, non-high pathway coverage substantially exceeds high-outcome coverage in all three chains (TL: 0.816 vs. 0.652; VL: 0.827 vs. 0.566; IL: 0.842 vs. 0.618), and more non-high pathways are identified. This asymmetry reflects a fundamental property of complex social phenomena: there are more ways to fail than to succeed. Critically, non-high pathways are not logical negations of high pathways. NL1 ($\sim\text{RE} \cdot \sim\text{BPE}$) produces a non-high technology-chain transition without requiring the absence of network linkage capability. Firms can therefore fail to leapfrog despite possessing strong network capability if platform enablement is absent. This directional asymmetry, which regression's symmetric coefficient estimation cannot capture, is itself a substantive theoretical finding rather than a methodological artifact.

Cross-Chain Managerial Signpost. The three cross-chain regularities identified above carry direct implications for practitioners navigating China's autonomous driving platform ecosystem, which are briefly summarized here and developed in full in Section 7.2. For complementor firms, the chain-specificity finding implies that capability investment should be dimension-selective rather than uniform: network linkage capability for firms targeting technology-chain leapfrogging, policy responsiveness for value-chain transitions, and either pathway for institutional-chain transitions, depending on the firm's relational endowment. Spreading limited capability-building resources evenly across all three strategic response capabilities is unlikely to produce leapfrog outcomes in any chain. For platform orchestrators, the universal structural prerequisite finding implies that governance design should deliver both rule clarity and resource provisioning simultaneously; the absence of either creates the joint-deficiency condition ($\sim\text{RE} \cdot \sim\text{BPE}$) that is the single strongest predictor of complementor stagnation across all three chains. For government agencies and policy-makers, the prominence of policy responsiveness as a core condition for value-chain and

institutional-chain transitions suggests that demonstration zone policies and standardization programs function not merely as regulatory instruments but as commercial accelerators and institutional entrepreneurship enablers: a governance function that justifies sustained policy investment in dual-governance platform contexts.

6.6. Findings vis-à-vis Prior Studies

The chain-specific and cross-chain findings reported in Sections 6.2–6.5 can be positioned within the existing platform-growth literature through three points of convergence and three points of divergence. This comparative exercise responds to the substantive question of what the present study adds to, and where it departs from, what is already known.

Convergence 1: Platform enablement as a structural prerequisite. The finding that platform enablement constitutes a necessary structural condition for leapfrog growth converges with Boudreau (2010) and Cennamo (2021), both of whom demonstrate that platform-mediated access fundamentally reshapes the strategic action set available to complementors, expanding the range of technically admissible moves for embedded firms while foreclosing it for non-embedded ones. The present study extends this consensus in one important respect: the necessary structural condition is not a homogeneous enabling environment but a dual-input construct. Rule-based and business platform enablement are empirically non-interchangeable; their joint presence, rather than either alone, constitutes the structural floor below which leapfrog transitions do not occur. This disaggregation was theoretically anticipated but had not previously been operationalized and tested in a configurational framework.

Convergence 2: Network linkage as the modal mechanism for technology-chain transition. The centrality of network linkage capability in technology-chain transition echoes Jacobides et al. (2018) and Yap et al. (2022), who argue on conceptual grounds that modular architectural diffusion is inherently a multi-party achievement: technical standards propagate not through unilateral superiority but through governed coalition-building across platform partners, OEM integrators, and scenario operators. The present study provides the first large-N configurational evidence that directly substantiates these largely conceptual claims: NLC appears as a core condition in five of six high-TL configurations, with a unique coverage substantially exceeding that of any alternative capability. This convergence is theoretically significant because it corroborates a widely cited but empirically thin claim in the platform ecosystem literature.

Convergence 3: Equifinality in institutional outcomes. The equifinality identified for institutional-chain transition—where network linkage and policy responsiveness constitute equally viable pathways anchored in dual-platform enablement—resonates with Misangyi et al. (2017) and Park et al. (2020), both of whom demonstrate that institutional outcomes in complex organizational settings typically admit multiple causally sufficient paths. The present finding extends this methodological insight to the specific domain of platform-mediated institutional co-construction, confirming that equifinality is not a statistical artifact but a theoretically meaningful property of the governance processes through which complementors transition from regulatory compliance toward standard co-authorship.

Divergence 1: Rule-based enablement as credentialing, not only generativity. Ofe and Sandberg (2022) theorize rule-based platform governance primarily as a generativity mechanism: clear rules create the institutional space within which complementors innovate freely. Our results reveal a second, distinct function that operates on a different chain. In dual-governance contexts—where private platform certification and public regulatory standing are mutually reinforcing—rule-based enablement also functions as a credentialing mechanism that embeds complementors in the private governance processes through which institutional-chain repositioning occurs. Generativity and credentialing are not mutually

exclusive; they operate through the same institutional clarity but activate different capability pathways and produce different forms of transformation. This functional distinction was not anticipated in Ofe and Sandberg's single-governance case study context and represents a substantive theoretical extension of their framework.

Divergence 2: Policy responsiveness, not network linkage, anchors value-chain transition. The finding that policy responsiveness—rather than the resource-and-network logic implied by Sirmon et al. (2011) and the platform ecosystem literature more broadly—constitutes the modal core condition for value-chain transition is the sharpest empirical departure from prior theory. Sirmon et al.'s resource orchestration framework predicts that firms achieve hub-level value appropriation by accumulating and deploying tangible resource bundles through inter-organizational networks. Our results show that in China's autonomous driving market, institutionally mediated advantages—operating licenses, government procurement priority, and provincial pilot funding—confer commercial positioning more efficiently than direct network investment, because they simultaneously lower coordination friction across multiple potential partners at once. This divergence is not a refutation of resource orchestration logic but a context-sensitive boundary condition: the Chinese state's active industrial governance apparatus functions as a commercial accelerator that substitutes for the relational investment that network-building requires in liberal-market settings. Whether this substitution effect generalizes beyond dual-governance emerging-economy contexts is an empirically open question that replicative configurational research in alternative institutional settings should address.

Divergence 3: Platform-mediated conditions as a scope boundary for hidden champion theory. Simon's (2009) hidden champion theory predicts that sustained internal capability accumulation—deepening niche specialization, proprietary technical competence, and customer intimacy—constitutes a self-sufficient engine of niche leadership. Our results systematically disconfirm this prediction for platform-mediated complementors: no high-outcome configuration achieves leapfrog transition through internal capability alone, and the joint absence of platform enablement is the single most independently explanatory condition for leapfrog failure across all three chains. This is not a refutation of the hidden champion theory but a precise delineation of its scope conditions. The theory was designed for stable, closed product markets in which competitive advantage is internally generated, and market structure is transparent. Platform ecosystems violate both assumptions: advantage is co-produced through ecosystem embeddedness, and market structure is continuously redefined by platform orchestrators. The present findings, therefore, specify the institutional boundary at which hidden champion theory requires augmentation, namely, wherever platform governance constitutes a *de facto* precondition for market access and growth.

7. Conclusions

This study set out to ask not whether platform enablement drives complementor growth, but which combinations of enablement types and strategic response capabilities activate which forms of leapfrog transformation. The configurational analysis of 374 autonomous driving complementor firms in China yields four conclusions that collectively reframe how platform-mediated firm growth should be theorized and studied.

First, leapfrog growth is a three-dimensional phenomenon: technology-chain, value-chain, and institutional-chain transitions are empirically separable outcomes, each anchored in a qualitatively different locus of ecological niche repositioning, and none can be recovered by collapsing them into a composite performance construct. Second, platform enablement is a universal structural prerequisite, but operates in dual-input form: rule-based and business platform enablement activate different capability-development pathways, and

their joint absence is the single most explanatory condition for leapfrog failure across all three chains. Third, each leapfrog dimension is governed by a distinctive capability logic: technology-chain transitions are network-linkage-driven; value-chain transitions are policy-responsiveness-anchored; institutional-chain transitions exhibit genuine equifinality between both pathways, with dual-platform enablement as the non-negotiable structural floor. Fourth, the configurational logic is asymmetric: the conditions sufficient for success are structurally independent of those sufficient for failure, and regression-based symmetry assumptions would systematically misrepresent both.

7.1. Theoretical Contributions

This study makes three theoretical contributions to the intersecting studies on platform governance, dynamic capabilities, and firm growth, advanced within the scope conditions of China's autonomous driving ecosystem during 2024–2026.

First, we operationalize platform enablement as a dual-input construct distinguishing rule-based and resource-based dimensions. We demonstrate that these two enablement types activate qualitatively distinct capability pathways and drive categorically different leapfrog transition dimensions, extending Gawer's (2021) platform boundary theory and Boudreau's (2010) access-versus-control framework by connecting enablement mechanisms to specific firm-level outcomes through configurational pathways.

Second, we construct a three-capability–three-transition matching model that reveals dimension-specific correspondences between strategic response capabilities and leapfrog outcomes. The model complicates the single-mediator paradigm dominating capability-based growth research and extends dynamic capabilities theory (Teece et al., 1997; Schilke et al., 2018) by identifying three functionally differentiated capability types, each corresponding to a distinct form of ecological niche repositioning.

Third, by situating the analysis in a paradigmatic case of dual institutional governance, we advance the inquiry from “whether platform enablement works” to “under which configurational conditions it works most effectively.” This contribution engages the Administrative Sciences agenda on governance, sustainability, and digital transformation, extending recent work in this outlet (Kankam-Kwarteng et al., 2026) toward a configurational, dual-enablement perspective on platform-mediated firm growth, and responds to calls for context-specific platform governance theorization (Chen et al., 2021). The cross-context transferability of these contributions is bounded by the scope conditions discussed in Section 7.3.

7.2. Practical Implications

The configurational findings translate into dimension-specific guidance for three audiences in the Chinese autonomous driving platform ecosystem; their transferability to other contexts depends on the degree to which those contexts share the dual institutional governance dynamics examined here.

For complementor firms, capability investment should be dimension-selective: network linkage capability for technology-chain transitions (anchoring five of six TL pathways); policy responsiveness combined with organizational ambidexterity for value-chain transitions; and either network linkage or policy responsiveness for institutional-chain transitions, with dual-platform enablement as the structural precondition for both. Uniform capability accumulation across all five conditions yields diminishing returns.

For platform orchestrators, governance design should activate distinct complementor capability pathways rather than applying uniform resource provisioning. Certification processes should reward sustained network engagement; inter-complementor collaboration infrastructure should reduce coordination costs; and regulatory liaison mechanisms should

allow policy-responsive firms to contribute to governance co-evolution. Rule-based and business platform enablement strategies should be calibrated to the specific upgrading trajectories the platform seeks to stimulate.

For government agencies, the equifinality in institutional-chain transitions underscores the value of institutionalized—rather than ad hoc—consultative channels through which platform-engaged firms contribute to regulatory co-design: standardization committee seats, regulatory sandbox partnerships, and technical advisory roles. Demonstration zone policies function not merely as regulatory instruments but as commercial accelerators and institutional entrepreneurship enablers under dual-governance conditions.

7.3. Limitations and Future Research Directions

Three boundary conditions qualify the study's conclusions and motivate future research.

First, the cross-sectional design precludes strict causal inference about the temporal sequencing of leapfrog transitions, and the findings are bounded by three nested scope conditions: the dual-governance, high-complexity characteristics of autonomous driving; China's specific state-market institutional architecture, to which the prominence of policy responsiveness may be particularly sensitive; and the early-maturation phase (2024–2026) during which configurations may not yet have stabilized. Future longitudinal panel studies and cross-national configurational comparisons are needed to determine which patterns are context-specific and which are more broadly transferable.

Second, the five antecedent conditions were selected to maintain parsimony within fsQCA sample-size constraints, and the study relies solely on set-theoretic analysis without variance-based triangulation. Future research incorporating structural platform characteristics (openness, network centrality) as additional conditions, or applying hierarchical moderated regression and structural equation modeling to the dominant interaction structures ($RE \times NLC$, $BPE \times PR$, $RE \times BPE \times PR$), would strengthen confidence in the configurational framework and delineate the boundary conditions of each analytical approach.

Third, pathway labeling and interpretation reflect theoretically grounded synthesis rather than direct causal identification. Alternative interpretive frames remain possible and should be explored as cross-context configurational evidence accumulates.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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

Abbreviations

The following abbreviations are used in this manuscript:

ADS	Autonomous Driving System
API	Application Programming Interface
AVE	Average Variance Extracted
BPE	Business Platform Enablement
CFA	Confirmatory Factor Analysis
CMB	Common Method Bias
CR	Composite Reliability
EFA	Exploratory Factor Analysis
fsQCA	Fuzzy-Set Qualitative Comparative Analysis
HTMT	Heterotrait–Monotrait Ratio
IL	Institutional-Chain Transition
INUS	Insufficient but Non-redundant part of an Unnecessary but Sufficient condition
MIIT	Ministry of Industry and Information Technology
NLC	Network Linkage Capability
OA	Organizational Ambidexterity
OEM	Original Equipment Manufacturer
PR	Policy Responsiveness
PRI	Proportional Reduction in Inconsistency
QCA	Qualitative Comparative Analysis
RE	Rule-Based Enablement
SEM	Structural Equation Modeling
TL	Technology-Chain Transition
VL	Value-Chain Transition

Appendix A

Table A1. Basic Information of the Formal Survey Sample ($N = 374$).

Characteristic	Category	Frequency	Percentage (%)
Respondent gender	Male	253	67.65
	Female	121	32.35
Respondent age	Under 30	41	10.96
	30–40	161	43.05
	41–50	119	31.82
	Over 50	53	14.17
Tenure with current company	Less than 3 years	52	13.90
	3–5 years	130	34.76
	6–10 years	134	35.83
	More than 10 years	58	15.51
Respondent position	General Manager/CEO	33	8.82
	Vice President/VP	50	13.37
	CTO/Technical Director	85	22.73
	Strategy Director	98	26.20
	Product Lead/Department Manager	108	28.88

Table A1. Cont.

Characteristic	Category	Frequency	Percentage (%)
Company age (years)	≤5	48	12.83
	6–10	183	48.93
	>10	143	38.24
Employee size	<50	86	22.99
	50–200	84	22.46
	200–500	103	27.54
	>500	101	27.01
Main business area	Low-speed unmanned delivery	148	39.57
	Park logistics/inspection	135	36.10
	Port/mining operations	81	21.66
	Other	10	2.67
Firm location	Beijing-Tianjin-Hebei region	80	21.39
	Yangtze River Delta region	127	33.96
	Pearl River Delta region	50	13.37
	Central/western pilot cities	78	20.86
	Northeast region	39	10.43
R&D expenditure ratio	<2%	50	13.37
	2–5%	105	28.07
	5–10%	115	30.75
	>10%	104	27.81
Participated in demo projects	Yes	242	64.71
	No	132	35.29
Platform-certified partner	Yes	248	66.31
	No	126	33.69
Participating in ≥2 platform ecosystems	Yes	178	47.59
	No	196	52.41
Total		374	100

Source: Compiled by the author.

Appendix B. Formal Survey Questionnaire

Note: This appendix presents the full 64-item formal survey instrument used for data collection, accompanied by two attention-check items that were excluded from substantive analysis. Items were originally developed in Chinese based on the extant literature and 37 in-depth firm interviews, refined through a pre-test, and translated into English following a standard translation–back-translation procedure. All substantive items use a 7-point Likert scale (1 = Strongly Disagree; 7 = Strongly Agree). Reverse-coded items are marked with an asterisk (*R) and were recoded prior to analysis using the transformation (8 – raw value). Attention-check items (ATT) were used solely for response-quality screening and are not counted among the 64 scale items.

Note on notation: Item codes in the questionnaire use three-letter prefixes for internal consistency during data collection: PE-RPE-xx for rule-based enablement items, PE-BPE-xx for business platform enablement items, and SR-NC-xx/SR-OA-xx/SR-PR-xx for the three strategic response capability items. In the theoretical discussion, results, and tables throughout the manuscript, these constructs are referred to by their simplified abbreviations: RE (rule-based enablement), BPE (business platform enablement), NLC (network linkage capability), OA (organizational ambidexterity), and PR (policy responsiveness). The questionnaire codes and the manuscript abbreviations refer to identical constructs.

Dear Manager,

This questionnaire, developed by our research team, aims to examine the growth pathways and underlying mechanisms of hidden champion firms within China's autonomous driving platform ecosystem. Your practical insights are critical for constructing a contextually grounded theory.

The questionnaire (i) consists of 64 substantive items developed from the literature and in-depth interviews with 37 firms, refined through a pre-test; (ii) employs a 7-point Likert scale (1 = Strongly Disagree, 7 = Strongly Agree); (iii) contains a small number of reverse-coded items marked with *R; and (iv) is fully anonymous, with responses used solely for academic research. Estimated completion time: 8–10 min.

Appendix B.1. Firm and Respondent Profile

Item	Options
Gender	☐ Male ☐ Female
Age	☐ ≤29 ☐ 30–39 ☐ 40–49 ☐ ≥50
Tenure in current firm	☐ <3 years ☐ 3–5 ☐ 6–10 ☐ >10
Position	☐ CEO/GM ☐ VP ☐ CTO/Tech Director ☐ Strategy Director ☐ Department Head
Years since firm founding	☐ ≤5 years ☐ 6–10 ☐ >10
Full-time employees	☐ <50 ☐ 50–200 ☐ 201–500 ☐ >500
Primary business area	☐ Low-speed unmanned delivery ☐ Park logistics/inspection ☐ Port/mining operations ☐ Other: _____
Firm location	☐ Beijing–Tianjin–Hebei ☐ Yangtze River Delta ☐ Pearl River Delta ☐ Central/Western pilot cities ☐ Other: _____
Participation in national/provincial demonstration projects	☐ Yes (specify: _____) ☐ No
Officially certified platform solution partner	☐ Yes ☐ No
R&D expenditure as % of revenue (past year)	☐ <2% ☐ 2–5% ☐ 5–10% ☐ >10%
Concurrent participation in ≥2 platform ecosystems	☐ Yes ☐ No

Appendix B.2. Formal Scale Items

Please rate each item based on your firm's actual situation over the past 12 months.

(1) Platform Ecosystem Context (PC)

No.	Code	Item (1–7)
1	PC-ED-03	Competitor strategies and new-entrant disruptions occur at very high frequency.
2	PC-ED-01	Product-technology iteration cycles in our industry are very short and hard to predict.
3	PC-ED-04	The infrastructure of the autonomous driving field is undergoing a paradigm-shift turbulence.
4	PC-ED-02	End-user demands and usage habits are changing drastically.
5	PC-PS-02	Relevant laws and regulations are becoming clearer and sending positive signals.
6	PC-PS-04	Government-led demonstration zones provide high-quality pilot facilities for firms.
7	PC-PS-01	Local governments show high tolerance toward innovative road testing or demonstration applications.
8	PC-PS-03	Fiscal subsidies or special funds targeting hidden champions are increasing.
9	PC-PO-03	Architectures across different platforms show increasing compatibility and neutrality.
10	PC-PO-01	The platform's core APIs maintain a high degree of openness and transparency.
11	PC-PO-04	The evolution of platform rules fully considers the survival space of SMEs.
12	PC-PO-02	The platform's access-review standards for complementors of different sizes are open and transparent.

(2) Platform Enablement (PE)

No.	Code	Item (1–7)
13	PE-RPE-04	The platform has established a clear framework for data security and compliance access.
14	PE-RPE-01	Technical standards and interface protocols provided by the platform are highly stable.
15	PE-RPE-07	The platform has transparent enforcement standards for violations and penalties.
16	PE-RPE-02	Rules formulated by the platform are compatible with our existing underlying technical solutions.
17	PE-RPE-05	The platform allows us to participate in setting certain key technical standards.
18	PE-RPE-03	Before updating rules, the platform communicates effectively with us and provides a grace period.
19	PE-RPE-06	The platform's rule mechanisms reduce our transaction and communication costs within the ecosystem.
20	PE-BPE-02	The simulation testing environment provided by the platform accurately recreates complex road scenarios.
21	PE-BPE-05	Through its endorsement, the platform helps us access core customers or government resources.
22	PE-BPE-01	The platform opens up high-quality real-time traffic-flow and road-test data.

No.	Code	Item (1–7)
23	PE-BPE-07	The platform and its ecosystem funds provide potential capital-operation or financing support.
24	PE-BPE-03	The computing resources provided by the platform meet our needs for large-scale algorithm training.
25	PE-BPE-06	The platform provides dedicated validation spaces or laboratories for our innovative solutions.
26	PE-BPE-04	The platform provides comprehensive development toolkits (SDKs) and technical solution guides.
ATT1	—	[Attention check—not counted among the 64 items] To ensure data quality, please select “5” for this item.

(3) Strategic Responsiveness (SR)

No.	Code	Item (1–7)
27	SR-NC-06	We maintain frequent and in-depth executive-level strategic communication with the platform operator.
28	SR-NC-02	We actively participate in cross-organizational collaborative innovation projects organized by the platform.
29	SR-NC-07	We are able to lead cross-organizational joint testing or demonstration operations.
30	SR-NC-01	We can quickly identify and connect with complementary partners within the platform.
31	SR-NC-05	We occupy a hub position for information exchange or resource linkage within the platform ecosystem.
32	SR-NC-03	We often collaborate with platform partners to develop joint solutions for end customers.
33	SR-NC-04	We can effectively leverage partners’ modular capabilities to optimize our own product performance.
34	SR-OA-03	Internal resource allocation can be flexibly reconfigured in response to changes in the platform environment.
35	SR-OA-06*R	Our organizational culture has a low tolerance for failure when exploring new platform scenarios.
36	SR-OA-01	We have set up a dedicated agile team responsible for responding to platform rule updates.
37	SR-OA-05	We can rapidly convert open platform resources into internal core technical assets.
38	SR-OA-02	We can simultaneously attend to underlying algorithm R&D and rapid delivery of commercial products.
39	SR-OA-04	We have established a joint review mechanism involving engineering, compliance, and strategy departments.
40	SR-OA-07	We are adept at finding room for innovation spillover while complying with platform rules.

No.	Code	Item (1–7)
41	SR-PR-04	We often proactively provide technical field-test data to regulatory authorities to support policy revision.
42	SR-PR-01	We can anticipate regulatory signals and preemptively arrange compliant technical solutions.
43	SR-PR-07	We can significantly reduce R&D costs through policy-based financing or subsidies.
44	SR-PR-03	We actively apply for demonstration licenses granted by governments within the platform ecosystem.
45	SR-PR-02	We are skilled at translating complex policy clauses into concrete product-technology lists.
46	SR-PR-05	We have a keen ability to interpret and provide feedback on government-issued industrial development guidelines.
47	SR-PR-06	Our technology-evolution direction remains consistently aligned with national or industry standards.
ATT2	—	[Attention check—not counted among the 64 items] Please read this item carefully and select “2”.

(4) Leapfrog Growth (LG)

No.	Code	Item (1–7)
48	LG-TL-02	Our core architecture has high generality across different platform scenarios.
49	LG-TL-05	Our patent portfolio covers essential underlying barriers that industry competitors must circumvent.
50	LG-TL-01	Our technical solutions have shifted from single-point customization to standardized modules.
51	LG-TL-07	Our solutions play a foundational and supporting role within the platform ecosystem.
52	LG-TL-03	We have achieved full decoupling of technical modules, allowing rapid integration by third parties.
53	LG-TL-06	Our technology-iteration speed significantly exceeds the industry average.
54	LG-TL-04	We lead the design or definition of key technical protocols in our domain.
55	LG-VL-02	Our revenue structure has shifted from pure hardware sales to a service revenue-sharing model.
56	LG-VL-05*R	Our brand has not yet become an industry-standard symbol of quality at a fair price in our niche market.
57	LG-VL-01	We have strong bargaining power and pricing autonomy in value distribution.
58	LG-VL-06	We occupy core high-value-added links within the ecosystem (e.g., system integration).
59	LG-IL-02	Competent authorities proactively consult our professional advice when formulating new rules.
60	LG-IL-07	Our corporate standards have effectively become the de facto benchmarks for the industry.

No.	Code	Item (1–7)
61	LG-IL-01	We have led the drafting of multiple key technical standards or white papers on behalf of the industry.
62	LG-IL-03	We deeply participate in national or local industry-governance working groups.
63	LG-IL-05	We have significant influence on the discourse on ecosystem-evolution paths at industry forums.
64	LG-IL-06	Through institutional collaboration, we successfully resolve common industry-wide access challenges.

Note on reverse-coded items. SR-OA-06*R and LG-VL-05*R are reverse-coded; for analysis, the transformation (8 – raw value) was applied so that higher recoded values consistently indicate higher levels of the underlying construct. The two attention-check items (ATT1, ATT2) were used for response-quality screening and are not included in the 64-item substantive scale.

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