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Driving Product Lifecycle Circularity through Circular Economy Adoption: The Roles of Innovation, Platforms, and Value Co-Creation

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ABSTRACT

Achieving product lifecycle circularity is a central challenge for firms transitioning toward sustainable production systems, particularly in manufacturing-intensive economies such as China. This study investigates how innovation-related capabilities, digital platforms, and value co-creation drive product lifecycle circularity through circular economy adoption. Using primary survey data collected from 395 respondents in China, the study applies Partial Least Squares Structural Equation Modeling (PLS-SEM) to test a comprehensive research framework. The results show that innovation network strength, innovation ecosystem dynamism, digital transformation readiness, platform-based business model innovation, and value co-creation capability positively influence circular economy adoption. Circular economy adoption, in turn, significantly enhances product lifecycle circularity. Product lifecycle orientation and collaborative consumption culture positively moderate this relationship. The study advances circular economy and innovation ecosystem literature by empirically establishing circular economy adoption as a key mechanism linking innovation, platforms, and co-creation to lifecycle circularity. Managers and policymakers can foster lifecycle circularity by strengthening innovation ecosystems, enhancing digital readiness, promoting platform-based models, and encouraging stakeholder co-creation. This study offers an integrated, ecosystem-oriented explanation of product lifecycle circularity and provides empirical evidence from China, a critical context for global circular economy transitions.

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1. Introduction

The transition toward a circular economy has emerged as a critical response to escalating resource scarcity, environmental degradation, and inefficiencies embedded in linear production and consumption systems. The circular economy advocates regenerative production models that emphasize resource efficiency, waste minimization, and value retention across product lifecycles through reuse, remanufacturing, and recycling (Geissdoerfer et al., 2017; Korhonen et al., 2018; Lieder & Rashid, 2016). For manufacturing-intensive economies, achieving circularity at the product lifecycle level has become a strategic priority rather than a purely environmental concern (Acerbi & Taisch, 2020; Pieroni et al., 2021).

China represents a particularly relevant context for examining circular economy transitions due to its scale of industrial production, resource consumption, and policy-driven sustainability agenda. The country has increasingly emphasized circular economy adoption as a national development strategy, integrating digitalization, innovation, and ecosystem collaboration into industrial transformation pathways (Medaglia et al., 2024; Nambisan et al., 2019). However, while circular economy principles are widely promoted, translating these principles into tangible product lifecycle circularity outcomes remains a persistent challenge for firms operating within complex industrial ecosystems (Genovese et al., 2017; Stucki et al., 2023).

Recent literature suggests that circular economy adoption does not occur in isolation but is shaped by innovation ecosystems, digital readiness, and collaborative value creation mechanisms. Innovation ecosystem theory emphasizes that firms depend on interconnected networks of partners, institutions, and technologies to access complementary knowledge and capabilities necessary for circular transitions (Adner & Kapoor, 2009; Jacobides et al., 2018). Strong innovation networks and dynamic ecosystems enhance firms' capacity to implement circular practices, particularly in technologically intensive environments (Bertrand-Cloodt et al., 2011; Del Vecchio et al., 2020).

Digital transformation further strengthens circular economy implementation by enabling lifecycle monitoring, data integration, and coordination across organizational and supply chain boundaries (Bhatti & Nawaz, 2020; Kristoffersen et al., 2020; Vial, 2021; Westerman et al., 2011). Organizational readiness for digital transformation reflects leadership commitment, technological capability, and cultural openness, which collectively determine firms' ability to operationalize circular strategies at scale (Chwiłkowska-Kubala et al., 2023; Michelotto & Joia, 2024). In parallel, platform-based business models have gained prominence by facilitating multi-actor interaction, resource sharing, and service-oriented value propositions that align closely with circular economy objectives (Clauss, 2016; Foss & Saebi, 2016; Nawab et al., 2021; Ranta et al., 2021).

Value co-creation theory complements these perspectives by highlighting the active role of customers and stakeholders in jointly creating sustainable value(Dhivya et al., 2023; Ragmoun, 2024; Ragmoun & Ben-Salha, 2024). Circular economy transitions require collaborative engagement across ecosystems to co-design solutions, share responsibilities, and embed sustainability across product lifecycles (Aarikka-Stenroos et al., 2021; Ranjan & Read, 2014). Such collaborative capabilities are particularly relevant in platform-mediated and digitally enabled environments, where user participation and shared use models support lifecycle extension (Hamari et al., 2015).

Despite growing scholarly attention, existing research remains fragmented in explaining how innovation, digital platforms, and value co-creation jointly drive product lifecycle circularity through circular economy adoption, especially in the Chinese context. Prior studies often examine these drivers in isolation, overlooking their integrated and mediating relationships (Acerbi & Taisch, 2020; Jesus & Jugend, 2021). Addressing this gap, the present study develops and empirically tests a comprehensive framework that positions circular economy adoption as a central mechanism linking innovation network strength, ecosystem dynamism, digital transformation readiness, platform-based business model innovation, and value co-creation to product lifecycle circularity in China. By doing so, this study contributes to the circular economy and sustainability literature by offering a holistic, ecosystem-oriented explanation of lifecycle circularity and by providing empirical evidence from a major emerging economy undergoing rapid digital and industrial transformation.

2. Theoretical Framework

This study is anchored in circular economy theory, innovation ecosystem theory, digital transformation theory, and value co-creation logic to explain how firms achieve product lifecycle circularity through circularity adoption. Circular economy theory frames sustainability as a regenerative system that emphasizes resource efficiency, waste minimization, and lifecycle extension through reuse, remanufacturing, and recycling (Geissdoerfer et al., 2017; Korhonen et al., 2018; Lieder & Rashid, 2016). From this perspective, circular economy adoption represents a strategic transformation requiring coordinated technological, organizational, and relational capabilities (Acerbi & Taisch, 2020; Pieroni et al., 2021). Innovation ecosystem theory highlights that circular transitions are embedded within networks of firms, institutions, and technologies, where access to complementary resources and knowledge is critical (Adner & Kapoor, 2009; Jacobides et al., 2018). Strong innovation networks and ecosystem dynamism facilitate the diffusion and implementation of circular practices, particularly in manufacturing-intensive contexts such as China (Bertrand-Cloodt et al., 2011; Del Vecchio et al., 2020).

Digital transformation theory further explains how organizational readiness enables firms to operate circular strategies. Digital technologies support lifecycle monitoring, coordination, and data-driven decision-making, thereby strengthening circular economy adoption (Kristoffersen et al., 2020; Vial, 2021; Westerman et al., 2011). Digital transformation readiness reflects leadership commitment, technological capability, and cultural openness, which are essential for embedding circular practices at scale (Chwiłkowska-Kubala et al., 2023; Michelotto & Joia, 2024). Platform-based business model innovation extends this logic by emphasizing ecosystem orchestration and multi-actor value creation(Chen et al., 2025; N et al., 2024). Platforms enable access-based consumption, resource sharing, and service-oriented models that are central to circular economy implementation (Clauss, 2016; Foss & Saebi, 2016; Ranta et al., 2021). Complementing this, value co-creation theory highlights the role of stakeholder collaboration in co-designing and scaling circular solutions across product lifecycles (Aarikka-Stenroos et al., 2021; Ranjan & Read, 2014). The framework positions circular economy adoption as the key mediating mechanism linking innovation, digital readiness, platforms, and value co-creation to product lifecycle circularity, while platform lifecycle orientation and collaborative consumption culture shape the strength of this relationship (Cennamo et al., 2020; Hamari et al., 2015).

2.1. Hypotheses Development

2.1.1. Institutional Support for Sustainability and Circular Economy Adoption

Institutional environments play a decisive role in shaping firms' sustainability-oriented behaviors by setting regulatory expectations, normative pressures, and incentive structures. Institutional support in the form of environmental regulations, policy guidance, and stakeholder pressure has been shown to accelerate firms' engagement in circular economy practices, particularly in emerging and transition economies where state involvement is prominent (Delmas & Toffel, 2004; DiMaggio & Powell, 2000; North, 1990; Wang, Gillani, Balsalobre-Lorente, et al., 2024). In the Chinese context, strong governmental intervention and sustainability-oriented industrial policies provide a conducive environment for firms to adopt circular economy principles as part of their strategic and operational decisions (Makohon, 2021; Medaglia et al., 2024). Accordingly, this study posits: H1: Institutional Support for Sustainability positively influences Circular Economy Adoption among Chinese firms.

2.1.2. Innovation and Eco-Design as Drivers of Circular Economy Adoption

Innovation capabilities and eco-design practices enable firms to redesign products, processes, and materials to support reuse, remanufacturing, and recycling. Prior research highlights that innovation-driven design choices are fundamental to embedding circularity into business operations and value chains (Geissdoerfer et al., 2017; Lieder & Rashid, 2016; Makohon, 2021; Medaglia et al., 2024; Pieroni et al., 2021). In manufacturing-intensive economies such as China, innovation and eco-design serve as critical enablers for transitioning from linear to circular production systems (Acerbi & Taisch, 2020; Amin et al., 2024). Thus, the following hypothesis is proposed: H2: Innovation and Eco-Design positively influence Circular Economy Adoption in Chinese firms.

2.1.3. Digital Technology Readiness and Circular Economy Adoption

Digital technologies enhance firms' ability to collect, process, and utilize information across supply chains, thereby facilitating circular strategies such as resource tracking, lifecycle management, and waste reduction. Technologies associated with Industry 4.0 strengthen organizational readiness for circular transformation by improving coordination, transparency, and process efficiency (Ghadge et al., 2020; Kristoffersen et al., 2020; Sadiq et al., 2024; Vial, 2021; Yang, Shafiq, Sharif, et al., 2024). In China's rapidly digitalizing industrial landscape, digital technology readiness is increasingly recognized as a prerequisite for effective circular economy adoption (Mitrofanova et al., 2024; Nemilentseva et al., 2024).

Hence, this study hypothesizes: H3: Digital Technology Readiness positively influences Circular Economy Adoption among Chinese firms.

2.1.4. Platform-Based Business Model Innovation and Circular Economy Adoption

Platform-based business models enable firms to orchestrate multi-actor ecosystems, enhance resource sharing, and support value creation beyond firm boundaries. Such models are particularly relevant for circular economy implementation, as they facilitate collaboration, scalability, and integration across product lifecycles (Jacobides et al., 2018; Nambisan et al., 2019; Wang, Gillani, Razzaq, et al., 2024). Prior studies suggest that platform-enabled business model innovation supports circular practices by enabling reuse, service-based offerings, and ecosystem-level coordination (Del Vecchio et al., 2020; Ranta et al., 2021). Accordingly, the following hypothesis is advanced: H4: Platform-Based Business Model Innovation positively influences Circular Economy Adoption in the Chinese context.

2.1.5. Value Co-Creation and Circular Economy Adoption

Value co-creation emphasizes active collaboration among firms, customers, and stakeholders in generating shared value. In circular economy systems, co-creation supports resource efficiency, knowledge sharing, and stakeholder engagement across the value network (Aarikka-Stenroos et al., 2021; Ranjan & Read, 2014). Empirical evidence suggests that collaborative value creation mechanisms strengthen firms’ capacity to adopt and sustain circular practices, particularly in complex industrial ecosystems (Jesus & Jugend, 2021; Ranta et al., 2021). Therefore, this study proposes: H5: Value Co-Creation positively influences Circular Economy Adoption among Chinese firms.

2.1.6. Circular Economy Adoption and Product Lifecycle Circularity

Circular economy adoption reflects firms’ strategic commitment to closing material loops, optimizing resource use, and extending product lifecycles. Product lifecycle circularity captures the degree to which products are designed, used, recovered, and reintegrated into production systems. Prior research consistently indicates that effective circular economy adoption translates into higher lifecycle circularity by embedding circular principles across design, production, use, and end-of-life stages (Genovese et al., 2017; Korhonen et al., 2018; Stucki et al., 2023). In China’s manufacturing-driven economy, this relationship is particularly salient. Thus, the following hypothesis is formulated: H6: Circular Economy Adoption positively influences Product Lifecycle Circularity in Chinese firms.

2.1.7. Moderating Role of Platform Lifecycle Orientation

Platform lifecycle orientation reflects the extent to which firms strategically manage platforms across different lifecycle stages. A strong platform orientation enhances the effectiveness of circular strategies by aligning digital infrastructures with lifecycle-based value creation (Cennamo et al., 2020; Westerman et al., 2011). As platforms mature, their ability to support circular coordination and resource optimization increases, strengthening the impact of circular economy adoption on lifecycle outcomes. Accordingly, this study hypothesizes: H7: Platform Lifecycle Orientation positively moderates the relationship between Circular Economy Adoption and Product Lifecycle Circularity in China.

2.1.8. Moderating Role of Circular Co-Creation Capability

Circular co-creation capability reflects firms’ ability to collaboratively design, implement, and scale circular solutions with ecosystem partners. Strong co-creation capabilities enhance firms’ ability to translate circular strategies into tangible lifecycle outcomes by mobilizing complementary resources and knowledge (Aarikka-Stenroos et al., 2021; Yaghmaie & Vanhaverbeke, 2019). In the Chinese industrial ecosystem, where inter-firm collaboration is increasingly emphasized, co-creation capabilities are expected to amplify the effectiveness of circular economy adoption. Hence, the final hypothesis is proposed: H8:

Circular Co-Creation Capability positively moderates the relationship between Circular Economy Adoption and Product Lifecycle Circularity among Chinese firms.

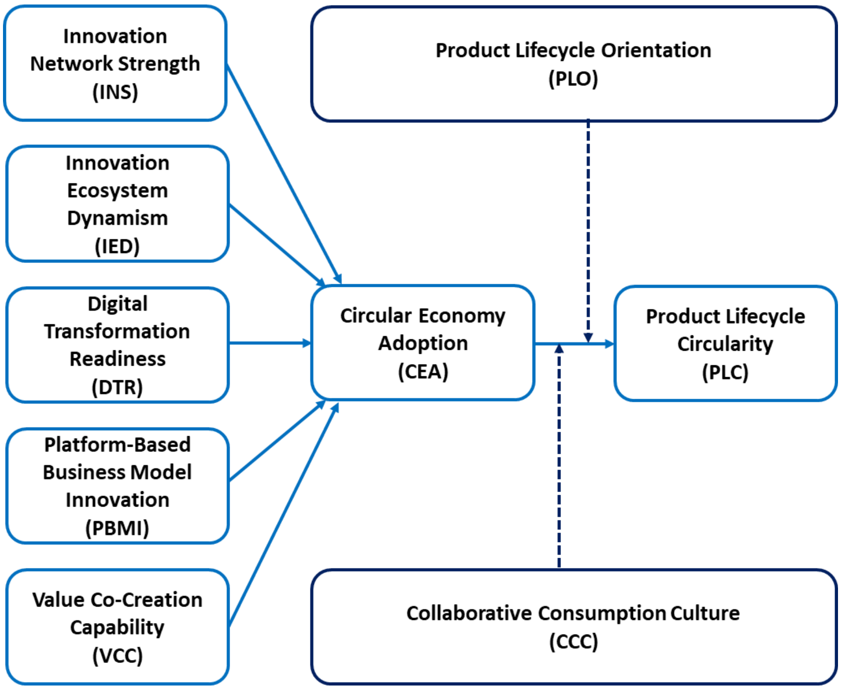

Figure 1: Conceptual Framework of the Study

3. Data and Methodology

3.1. Research Design and Data Collection

This study adopts a quantitative, cross-sectional research design to empirically examine the relationships among innovation, digital platforms, value co-creation, circular economy adoption, and product lifecycle circularity in the Chinese context. A survey-based approach was considered appropriate given the study's objective of testing theoretically grounded relationships using latent constructs and structural equation modeling (Hair et al., 2017; Hair et al., 2019).

Primary data were collected from 395 respondents in China, comprising managers, sustainability officers, operations managers, and senior professionals involved in innovation, digital transformation, product lifecycle management, and circular economy initiatives within their organizations. China was selected as the empirical context due to its manufacturing intensity, rapid digital transformation, and strong policy emphasis on circular economy development (Medaglia et al., 2024; Nemilentseva et al., 2024). Data collection was conducted using a structured questionnaire administered electronically, ensuring respondent anonymity and voluntary participation.

3.2. Measurement Development

Consistent with established scale development and validation practices, the constructs used in this study were developed by synthesizing measurement items from multiple foundational studies rather than adopting a single existing scale (Churchill, 1979; DeVellis & Thorpe, 2021; Hinkin, 1998; MacKenzie et al., 2011). This approach is particularly appropriate for complex and evolving research domains such as circular economy adoption, platform-based business models, and value co-creation, where no single validated scale fully captures the construct domain (Acerbi & Taisch, 2020; Jesus & Jugend, 2021). All constructs were operationalized as reflective measures, and items were adapted and contextualized to align with the Chinese industrial and organizational environment. A five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree") was used to measure all items, which is consistent with prior management and sustainability research (Hair et al., 2019; Nunnally, 1994). To ensure content validity, the initial pool of items was reviewed by academic experts and industry practitioners with expertise in circular economy, innovation management, and digital transformation. Minor wording refinements were made to improve clarity and contextual relevance (DeVellis & Thorpe, 2021; Hinkin, 1998). A pilot test was subsequently conducted with a small subset of respondents to confirm item comprehensibility and consistency before full-scale data collection.

4. Data Analysis Technique

The proposed research model was tested using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS. PLS-SEM was selected due to its suitability for theory development, prediction-oriented research, and models involving multiple constructs and moderating effects (Hair et al., 2017; Hair et al., 2019). This method is also appropriate when the research focuses on explaining variance in key endogenous constructs such as circular economy adoption and product lifecycle circularity.

The analysis followed a two-step procedure. First, the measurement model was assessed for internal consistency reliability, convergent validity, and discriminant validity using Cronbach's alpha, composite reliability, average variance extracted (AVE), the Fornell–Larcker criterion, the heterotrait–monotrait (HTMT) ratio, and cross-loadings (Fornell & Larcker, 1981; Hair et al., 2019; Henseler et al., 2014). Second, the structural model was evaluated by examining path coefficients, t-statistics, p-values, and moderation effects using a bootstrapping procedure with a large number of subsamples (Hair et al., 2019).

4.1. Common Method Bias and Multicollinearity

Given the use of self-reported survey data, potential common method bias was addressed through procedural and statistical remedies. Procedurally, respondents were assured of anonymity, and construct items were carefully worded to reduce evaluation apprehension. Statistically, common method bias was assessed using the full collinearity variance inflation factor (VIF) approach, with all values remaining below recommended thresholds, indicating no serious concern (Kock, 2015; Podsakoff et al., 2024). Multicollinearity was further examined using VIF values for all predictor constructs, which were within acceptable limits, confirming that collinearity did not bias the estimation results (Hair et al., 2019). Overall, the adopted methodology provides a robust empirical basis for examining how innovation, platforms, and value co-creation drive product lifecycle circularity through circular economy adoption in the Chinese context.

5. Results

The results in Table 2 indicate that the measurement model demonstrates strong convergent validity for all constructs, including Circular Co-Creation Capability (CCC), Circular Economy Adoption (CEA), Digital Transformation Readiness (DTR), Innovation and Eco-Design (IED), Institutional Support (INS), Platform-Based Business Model Innovation (PBMI), Product Lifecycle Circularity (PLC), Platform Learning Orientation (PLO), and Value Co-Creation (VCC). All indicator loadings range from 0.787 to 0.852, exceeding the recommended threshold of 0.70, which confirms that the items reliably represent their respective constructs and no indicator removal is required. Internal consistency reliability is well established, as Cronbach's alpha values range between 0.836 and 0.876 and composite reliability (CR) values range from 0.841 to 0.881, all surpassing the minimum acceptable level of 0.70, indicating consistent measurement across items. Furthermore, the average variance extracted (AVE) values for all constructs range from 0.646 to 0.687, exceeding the 0.50 criterion, which demonstrates that each construct explains more than half of the variance in its indicators. Overall, these results confirm that the constructs exhibit adequate reliability and convergent validity, supporting the robustness of the measurement model for subsequent structural model analysis.

The HTMT results in Table 3 provide strong evidence of discriminant validity among all constructs in the measurement model, including CCC, CEA, DTR, IED, INS, PBMI, PLC, PLO, and VCC. All HTMT values are well below the conservative threshold of 0.85, and even below the more lenient cutoff of 0.90, indicating that each construct is empirically distinct from the others. The highest HTMT value is observed between Circular Economy Adoption (CEA) and Product Lifecycle Circularity (PLC) at 0.585, which remains comfortably within acceptable limits and is theoretically reasonable given their conceptual relatedness. Similarly, moderate HTMT values between CEA and DTR (0.571) and between CEA and VCC (0.448) reflect meaningful associations without indicating redundancy. All remaining construct pairs exhibit low HTMT ratios, generally below 0.40, further confirming adequate discriminant validity. Overall, these findings demonstrate that the constructs capture unique conceptual domains and that the measurement model satisfies the discriminant validity requirements, supporting the suitability of the constructs for subsequent structural model analysis.

Table 1
Construct Development and Validation Framework with Supporting Literature

Core Term	Included Steps	Sub-steps	Short Definition, Cut-Points, and Key References
Conceptual Validation	• Domain specification; • Item generation from literature;	• Theoretical grounding • Construct boundary definition • Identification of dimensions • Item synthesis from prior studies	Establishes the conceptual meaning and domain boundaries of the construct and ensures that items adequately represent the construct's content. This stage is theory-driven and qualitative; no statistical cut-points apply. Widely recommended in scale development research (Churchill, 1979; Hinkin, 1998; DeVellis, 2016; MacKenzie et al., 2011).
Content Validation	Expert review / content validity	Expert assessment of relevance and clarity	
Instrument Pre-Testing	Pilot test / pretest	• Small-sample administration (typically 30–50 respondents) • Identification of ambiguous wording • Preliminary reliability assessment • Questionnaire refinement	Evaluates clarity, interpretability, and face validity of the instrument prior to full data collection. No strict thresholds apply; preliminary reliability values around 0.60–0.70 are generally acceptable at this stage (Hinkin, 1998; DeVellis, 2016).
Statistical Validation –	Reliability: Internal consistency assessment	• Cronbach's Alpha (α) • Composite Reliability (CR)	Assesses the internal consistency of items measuring a construct. Recommended cut-points are $\alpha \geq 0.70$ and CR between 0.70 and 0.95, with CR preferred in PLS-SEM (Hair et al., 2019; Nunnally & Bernstein, 1994).
Statistical Validation –	Convergent Validity: Indicator convergence assessment	• Outer (indicator) loadings • Average Variance Extracted (AVE)	Confirms that indicators converge to measure the same construct. Acceptable thresholds are indicator loadings ≥ 0.70 and AVE ≥ 0.50 (Fornell & Larcker, 1981; Hair et al., 2019).
Statistical Validation –	Discriminant Validity: Construct distinctiveness assessment	• Fornell–Larcker criterion • HTMT ratio • Cross-loadings	Ensures constructs are empirically distinct. Criteria include the square root of AVE exceeding inter-construct correlations, HTMT values ≤ 0.85 (strict) or ≤ 0.90 (acceptable), and higher loadings on the intended construct than on others (Fornell & Larcker, 1981; Henseler et al., 2015).
Statistical Validation –	Multicollinearity: Collinearity assessment	• Outer VIF (indicator level) • Inner VIF (structural level)	Examines redundancy among indicators and constructs to avoid estimation bias. VIF values below 3.3 (conservative) or 5.0 (acceptable) indicate no serious multicollinearity (Hair et al., 2019; Kock, 2015).
Statistical Validation –	Nomological Validity: Structural consistency with theory	• Path coefficients • Bootstrapped t-values and p-values • Mediation and moderation effects • R^2 and effect sizes (f^2)	Establishes whether constructs behave as predicted by theory within the structural model. Nomological validity is supported when hypothesized paths are significant ($t \geq 1.96$, $p < 0.05$) and exhibit meaningful explanatory power (Hair et al., 2019; MacKenzie et al., 2011).

Table 2

Convergent Validity Test

Constructs	items	Loading	Alpha	CR	AVE
CCC	CCC1	0.815	0.849	0.86	0.687
	CCC2	0.814			
	CCC3	0.833			
	CCC4	0.852			
CEA	CEA1	0.811	0.869	0.869	0.655
	CEA2	0.821			
	CEA3	0.808			
	CEA4	0.798			
	CEA5	0.808			
DTR	DTR1	0.815	0.84	0.843	0.675
	DTR2	0.829			
	DTR3	0.825			
	DTR4	0.818			
IED	IED1	0.796	0.863	0.869	0.646
	IED2	0.814			
	IED3	0.795			
	IED4	0.802			
	IED5	0.811			
INS	INS1	0.814	0.838	0.841	0.672
	INS2	0.837			
	INS3	0.827			
	INS4	0.802			
PBMI	PBMI1	0.802	0.875	0.881	0.665
	PBMI2	0.825			
	PBMI3	0.809			
	PBMI4	0.825			
	PBMI5	0.815			
PLC	PLC1	0.832	0.876	0.88	0.668
	PLC2	0.821			
	PLC3	0.815			
	PLC4	0.816			
	PLC5	0.802			
PLO	PLO1	0.827	0.843	0.852	0.679
	PLO2	0.834			
	PLO3	0.847			
	PLO4	0.787			
VCC	VCC1	0.83	0.836	0.842	0.669
	VCC2	0.827			
	VCC3	0.814			
	VCC4	0.801			

Table 3
HTMT Ratio

	CCC	CEA	DTR	IED	INS	PBMI	PLC	PLO	VCC
CCC									
CEA	0.393								
DTR	0.27	0.571							
IED	0.276	0.437	0.24						
INS	0.239	0.475	0.221	0.161					
PBMI	0.171	0.479	0.334	0.206	0.141				
PLC	0.202	0.585	0.341	0.312	0.249	0.263			
PLO	0.355	0.377	0.283	0.234	0.221	0.141	0.165		
VCC	0.201	0.448	0.268	0.241	0.177	0.191	0.263	0.181	

The Fornell–Larcker results in Table 4 confirm satisfactory discriminant validity for all constructs in the measurement model. The square roots of the AVE values, shown along the diagonal, are higher than the corresponding inter-construct correlations in each row and column. Specifically, the diagonal values for CCC (0.829), CEA (0.809), DTR (0.822), IED (0.804), INS (0.820), PBMI (0.816), PLC (0.817), PLO (0.824), and VCC (0.818) all exceed their respective correlations with other constructs. Although some constructs exhibit moderate correlations, particularly between CEA and PLC (0.515) and between CEA and DTR (0.490), these correlations remain lower than the square roots of their AVE values, indicating that each construct shares more variance with its own indicators than with other constructs.

Overall, the Fornell–Larcker criterion is fully satisfied, demonstrating that the constructs are empirically distinct and providing further support for the adequacy of discriminant validity in the measurement model.

Table 4
Fornell-Larcker

	CCC	CEA	DTR	IED	INS	PBMI	PLC	PLO	VCC
CCC	0.829								
CEA	0.338	0.809							
DTR	0.228	0.49	0.822						
IED	0.235	0.383	0.204	0.804					
INS	0.206	0.407	0.189	0.139	0.82				
PBMI	0.149	0.424	0.286	0.18	0.11	0.816			
PLC	0.18	0.515	0.295	0.276	0.218	0.234	0.817		
PLO	0.3	0.322	0.24	0.202	0.187	0.121	0.144	0.824	
VCC	0.172	0.386	0.231	0.211	0.152	0.167	0.229	0.153	0.818

The cross-loading results in Table 5 further confirm the discriminant validity of the measurement model. Each indicator loads highest on its respective construct compared to all other constructs, demonstrating that the items are strong representations of their intended latent variables. Specifically, items measuring CCC, CEA, DTR, IED, INS, PBMI, PLC, PLO, and VCC all exhibit their highest loadings on the corresponding constructs, with no problematic cross-loadings observed. While some items show moderate correlations with theoretically related constructs, such as between CEA and PLC or between DTR and PBMI, these cross-loadings remain substantially lower than the items' primary loadings. This pattern indicates that the indicators are not capturing unintended constructs and that construct boundaries are well maintained. Overall, the cross-loading analysis provides additional support for discriminant validity and confirms the robustness and clarity of the measurement model, justifying its use for subsequent structural model estimation.

5.1. Measurement Model

The measurement model demonstrates strong reliability and validity across all constructs included in the study. All indicator loadings are high, ranging approximately from 0.79 to 0.89, and exceed the recommended threshold of 0.70, indicating that each item loads strongly on its intended construct and adequately represents the underlying latent variable. The constructs Innovation Network Strength, Innovation Ecosystem Dynamism, Digital Transformation Readiness, Platform-Based Business Model Innovation, Value Co-Creation Capability, Circular Economy Adoption, Product Lifecycle Orientation, Collaborative Consumption Culture, and Product Lifecycle Circularity are all measured reflectively with well-balanced and consistent item loadings. Internal consistency reliability is well established, as evidenced by Cronbach's alpha and composite reliability values that are consistently above 0.80, confirming that the items within each construct are internally coherent. Convergent validity is also confirmed, with average variance extracted (AVE) values exceeding the minimum threshold of 0.50 for all constructs, indicating that each construct explains a substantial proportion of variance in its indicators. Overall, the measurement model satisfies accepted PLS-SEM criteria for indicator reliability, internal consistency, and convergent validity, providing a robust foundation for subsequent structural model analysis.

The path analysis results in Table 6 indicate strong empirical support for all hypothesized relationships in the structural model. Innovation Network Strength has a positive and significant effect on Circular Economy Adoption ($\beta = 0.269$, $p < 0.001$), demonstrating that stronger innovation linkages enhance firms' adoption of circular practices. Innovation Ecosystem Dynamism also shows a significant positive influence on Circular Economy Adoption ($\beta = 0.202$, $p < 0.001$), indicating that operating in dynamic and adaptive innovation environments facilitates circular transitions. Digital Transformation Readiness emerges as a strong predictor of Circular Economy Adoption ($\beta = 0.283$, $p < 0.001$), highlighting the importance of organizational preparedness for digital change. Platform-Based Business Model Innovation significantly enhances Circular Economy Adoption as well ($\beta = 0.245$, $p < 0.001$), suggesting that innovative, platform-oriented business models accelerate circular adoption. In addition, Value Co-Creation Capability positively and significantly influences Circular Economy Adoption ($\beta = 0.196$, $p < 0.001$), underscoring the role of stakeholder and user engagement in advancing circular practices.

Table 5
Cross Loadings

CCC		CEA	DTR	IED	INS	PBMI	PLC	PLO	VCC
CCC1	**0.815**	0.247	0.161	0.192	0.146	0.127	0.13	0.239	0.086
CCC2	**0.814**	0.303	0.224	0.216	0.136	0.163	0.135	0.26	0.169
CCC3	**0.833**	0.261	0.182	0.186	0.192	0.090	0.151	0.261	0.189
CCC4	**0.852**	0.307	0.192	0.189	0.197	0.119	0.174	0.238	0.126
CEA1	0.270	**0.811**	0.367	0.336	0.310	0.338	0.404	0.277	0.299
CEA2	0.273	**0.821**	0.402	0.312	0.352	0.399	0.438	0.245	0.348
CEA3	0.300	**0.808**	0.444	0.274	0.353	0.263	0.373	0.294	0.302
CEA4	0.258	**0.798**	0.399	0.315	0.318	0.373	0.418	0.275	0.292
CEA5	0.269	**0.808**	0.374	0.312	0.314	0.337	0.446	0.217	0.319
DTR1	0.180	0.408	**0.815**	0.148	0.121	0.248	0.24	0.208	0.211
DTR2	0.202	0.444	**0.829**	0.180	0.189	0.244	0.27	0.187	0.198
DTR3	0.172	0.370	**0.825**	0.176	0.170	0.198	0.161	0.194	0.191
DTR4	0.194	0.382	**0.818**	0.167	0.139	0.249	0.293	0.199	0.158
IED1	0.188	0.274	0.199	**0.796**	0.107	0.144	0.188	0.157	0.179
IED2	0.169	0.353	0.148	**0.814**	0.147	0.166	0.221	0.134	0.188
IED3	0.181	0.268	0.139	**0.795**	0.112	0.127	0.176	0.197	0.137
IED4	0.210	0.298	0.147	**0.802**	0.077	0.125	0.251	0.166	0.113
IED5	0.198	0.330	0.190	**0.811**	0.108	0.155	0.263	0.168	0.22
INS1	0.152	0.313	0.107	0.121	**0.814**	0.122	0.173	0.14	0.1
INS2	0.197	0.368	0.202	0.131	**0.837**	0.113	0.263	0.194	0.155
INS3	0.135	0.329	0.157	0.090	**0.827**	0.134	0.131	0.132	0.104
INS4	0.187	0.320	0.147	0.111	**0.802**	-0.013	0.136	0.14	0.136
PBMI1	0.035	0.300	0.225	0.141	0.048	**0.802**	0.203	0.026	0.112
PBMI2	0.135	0.334	0.256	0.167	0.031	**0.825**	0.157	0.107	0.128
PBMI3	0.120	0.325	0.259	0.147	0.110	**0.809**	0.208	0.154	0.119
PBMI4	0.131	0.408	0.216	0.141	0.122	**0.825**	0.217	0.091	0.2
PBMI5	0.174	0.345	0.218	0.140	0.124	**0.815**	0.167	0.11	0.107
PLC1	0.179	0.454	0.286	0.244	0.184	0.218	**0.832**	0.126	0.213
PLC2	0.193	0.464	0.223	0.236	0.201	0.228	**0.821**	0.127	0.199
PLC3	0.127	0.395	0.277	0.271	0.209	0.246	**0.815**	0.119	0.185
PLC4	0.125	0.375	0.217	0.18	0.166	0.131	**0.816**	0.083	0.157
PLC5	0.099	0.401	0.201	0.191	0.125	0.122	**0.802**	0.129	0.176
PLO1	0.26	0.262	0.196	0.169	0.185	0.094	0.131	**0.827**	0.1
PLO2	0.264	0.257	0.211	0.162	0.117	0.079	0.114	**0.834**	0.167
PLO3	0.239	0.284	0.214	0.214	0.133	0.121	0.128	**0.847**	0.126
PLO4	0.225	0.258	0.163	0.109	0.185	0.105	0.097	**0.787**	0.113
VCC1	0.167	0.347	0.262	0.203	0.144	0.157	0.196	0.153	**0.83**
VCC2	0.151	0.339	0.196	0.19	0.16	0.095	0.202	0.127	**0.827**
VCC3	0.124	0.294	0.157	0.162	0.073	0.189	0.21	0.1	**0.814**
VCC4	0.114	0.272	0.122	0.124	0.111	0.107	0.136	0.115	**0.801**

Circular Economy Adoption, in turn, has a strong and highly significant positive effect on Product Lifecycle Circularity ($\beta = 0.518$, $p < 0.001$), confirming it as a key mechanism through which upstream innovation and platform capabilities translate into lifecycle-level circular outcomes. The moderation analysis further reveals that Product Lifecycle Orientation positively moderates the relationship between Circular Economy Adoption and Product Lifecycle Circularity ($\beta = 0.179$, $p < 0.001$), indicating that firms with a stronger lifecycle-oriented mindset are better able to convert circular adoption into tangible circular lifecycle outcomes. Similarly, Collaborative Consumption Culture significantly strengthens the effect of Circular Economy Adoption on Product Lifecycle Circularity ($\beta = 0.123$, $p = 0.003$), suggesting that user openness to sharing and access-based consumption enhances the effectiveness of circular initiatives. Overall, the results provide robust support for the proposed model and highlight both organizational and cultural boundary conditions shaping the transition from circular adoption to product lifecycle circularity.

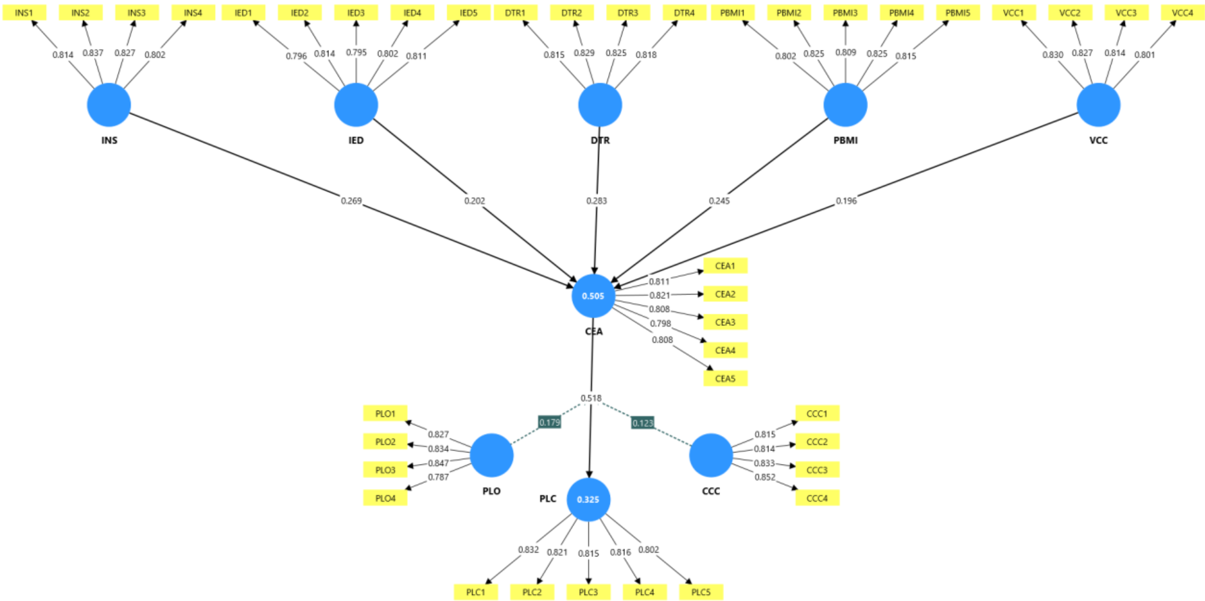

Figure 2: Measurement Model

Table 6
Path Analysis

Hypothesis		Beta	STDEV	T statistics	P values
H1	INS -> CEA	0.269	0.037	7.343	0.000
H2	IED -> CEA	0.202	0.040	5.052	0.000
H3	DTR -> CEA	0.283	0.038	7.349	0.000
H4	PBMI -> CEA	0.245	0.035	7.034	0.000
H5	VCC -> CEA	0.196	0.037	5.265	0.000
H6	CEA -> PLC	0.518	0.039	13.154	0.000
H7	PLO x CEA -> PLC	0.179	0.040	4.479	0.000
H8	CCC x CEA -> PLC	0.123	0.042	2.936	0.003

5.2. Structural Model

The structural model results provide strong support for the proposed theoretical relationships driving product lifecycle circularity through circular economy adoption. Innovation Network Strength, Innovation Ecosystem Dynamism, Digital Transformation Readiness, Platform-Based Business Model Innovation, and Value Co-Creation Capability all exhibit positive and statistically significant effects on Circular Economy Adoption, as indicated by substantial path coefficients and high t-values exceeding the critical threshold. Together, these innovation-, platform-, and capability-oriented factors explain a substantial proportion of variance in Circular Economy Adoption, with an R^2 value of 0.505, indicating moderate to strong explanatory power. Circular Economy Adoption, in turn, has a strong and highly significant positive effect on Product Lifecycle Circularity, confirming its central mediating role in translating upstream innovation and platform capabilities into circular outcomes across the product lifecycle. The R^2 value for Product Lifecycle Circularity is 0.325, suggesting that the model explains a meaningful share of variance in circularity performance. The moderating effects are also statistically significant, as Product Lifecycle Orientation positively strengthens the relationship between Circular Economy Adoption and Product Lifecycle Circularity, indicating that firms with a stronger lifecycle-oriented mindset are better able to convert circular economy adoption into tangible circularity outcomes. Similarly, Collaborative Consumption Culture significantly enhances the impact of Circular Economy Adoption on Product Lifecycle Circularity, highlighting the importance of user participation and shared consumption norms in amplifying circular outcomes. Overall, the structural model demonstrates strong predictive relevance and theoretical coherence, confirming that circular economy adoption acts as a key transmission mechanism through which innovation networks, digital readiness, platform-based models, and value co-creation jointly drive product lifecycle circularity.

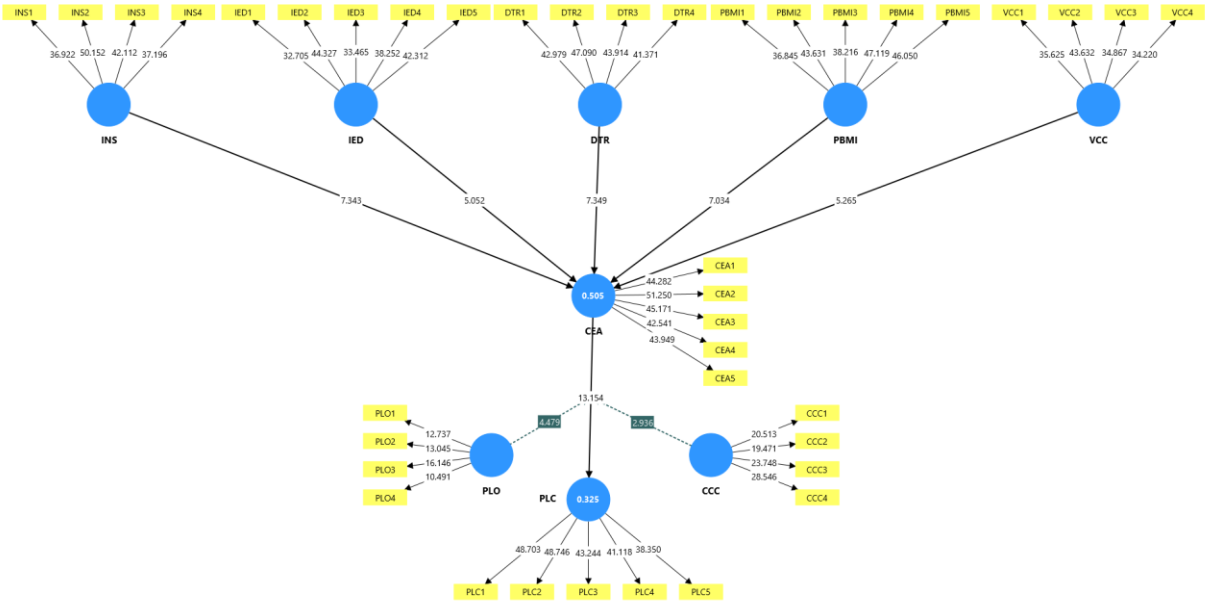

Figure 3: Structural Model

5.3. Discussion

The findings of this study provide robust empirical evidence on how innovation-, platform-, and collaboration-related capabilities drive product lifecycle circularity through circular economy adoption in the Chinese context. Consistent with circular economy theory, the results confirm that circular economy adoption is a central mechanism through which firms translate strategic and organizational capabilities into tangible lifecycle outcomes (Geissdoerfer et al., 2017; Lieder & Rashid, 2016; Stucki et al., 2023). The significant positive effects of innovation network strength and innovation ecosystem dynamism on circular economy adoption highlight the importance of ecosystem-level collaboration in supporting circular transitions. These findings align with innovation ecosystem theory, which emphasizes that access to external knowledge, complementary resources, and collaborative networks enhances firms' capacity to implement complex innovations such as circular practices (Adner & Kapoor, 2009; Jacobides et al., 2018). Prior studies have similarly shown that strong innovation networks and dynamic ecosystems facilitate sustainable innovation and performance outcomes, particularly in technology-intensive environments (Bertrand-Cloodt et al., 2011; Del Vecchio et al., 2020; Yang, Shafiq, Nazir, et al., 2024). The results extend this literature by demonstrating that such ecosystem conditions are particularly salient for circular economy adoption in China.

The positive relationship between digital transformation readiness and circular economy adoption underscores the enabling role of digital capabilities in operationalizing circular strategies. This finding corroborates earlier research suggesting that digital readiness strengthens firms' ability to integrate information, coordinate activities, and manage product lifecycles more effectively (Kristoffersen et al., 2020; Vial, 2021; Westerman et al., 2011). In line with recent studies, organizational readiness—rather than mere technology availability—emerges as a critical determinant of successful digital-enabled sustainability transitions (Chwiłkowska-Kubala et al., 2023; Michelotto & Joia, 2024). This is particularly relevant in China, where rapid digitalization amplifies the strategic importance of readiness for circular transformation (Mitrofanova et al., 2024; Nemilentseva et al., 2024). The significant influence of platform-based business model innovation on circular economy adoption supports the argument that platforms facilitate ecosystem orchestration and service-oriented value creation, which are essential for circular business models. This finding is consistent with prior research showing that platform-based models enable access-based consumption, resource sharing, and multi-actor coordination, all of which support circular objectives (Clauss et al., 2021; Foss & Saebi, 2016; Ranta et al., 2021). By empirically validating this relationship, the study advances the circular economy literature by positioning platforms as strategic enablers of circular adoption rather than as purely digital infrastructures (Centobelli et al., 2020; Nambisan et al., 2019).

The positive effect of value co-creation capability on circular economy adoption further highlights the relational dimension of circular transitions. Consistent with value co-creation theory, the findings suggest that active stakeholder involvement enhances firms' ability to co-design, implement, and scale circular solutions (Aarikka-Stenroos et al., 2021; Ranjan & Read, 2014). This result aligns with recent studies emphasizing the role of collaborative engagement in supporting circular economy practices within complex ecosystems (Jesus & Jugend, 2021; Ranta et al., 2021). Importantly, the strong positive relationship between circular economy adoption and product lifecycle circularity confirms that strategic adoption of circular principles translates into measurable lifecycle outcomes. This finding reinforces prior evidence that circular economy implementation improves lifecycle performance by embedding circular practices across design, production, use, and end-of-life stages (Genovese et al., 2017; Korhonen et al., 2018; Noshad et al., 2019). The result is particularly meaningful in the Chinese context, where achieving lifecycle-level circularity remains a key policy and managerial challenge (Medaglia et al., 2024).

The moderating effects further enrich the findings. The significant moderation of product lifecycle orientation strengthens the relationship between circular economy adoption and product lifecycle circularity, suggesting that firms with a stronger lifecycle perspective are better positioned to convert circular strategies into lifecycle outcomes. This supports prior work emphasizing the importance of aligning digital platforms and organizational strategies with lifecycle thinking (Cennamo et al., 2020; Westerman et al., 2011). Similarly, the moderating role of collaborative consumption culture indicates that user openness to sharing and access-based consumption enhances the effectiveness of circular economy adoption in driving lifecycle circularity, echoing earlier findings in the sharing and collaborative consumption literature (Hamari et al., 2015; Möhlmann, 2015). Overall, the findings provide an integrated explanation of how ecosystem conditions, digital readiness, platform innovation, and value co-creation jointly drive product lifecycle circularity through circular economy adoption in China. By empirically validating these relationships within a single framework, the study advances the circular economy literature from fragmented drivers toward a holistic, ecosystem-oriented understanding of lifecycle circularity.

6. Conclusion

This study examined how innovation, digital platforms, and value co-creation drive product lifecycle circularity through circular economy adoption in the Chinese context. Drawing on ecosystem, digital transformation, and circular economy perspectives, the findings demonstrate that innovation network strength, innovation ecosystem dynamism, digital transformation readiness, platform-based business model innovation, and value co-creation capability significantly enhance circular economy adoption. In turn, circular economy adoption strongly improves product lifecycle circularity. Moreover, product lifecycle orientation and collaborative consumption culture strengthen the effectiveness of circular economy adoption in translating strategic intent into lifecycle-level circular outcomes. Collectively, the results confirm that achieving lifecycle circularity requires not only technological and innovation capabilities but also ecosystem coordination and stakeholder engagement. By empirically validating these relationships within a single framework, the study advances understanding of how firms in China can operationalize circular strategies to achieve sustainable lifecycle performance.

6.1. Implications

This study contributes to the circular economy literature by positioning circular economy adoption as a central mediating mechanism linking innovation, digital readiness, platforms, and value co-creation to product lifecycle circularity. It extends innovation ecosystem and digital transformation research by demonstrating their joint relevance in explaining lifecycle-level sustainability outcomes rather than firm-level performance alone. The findings also enrich value co-creation theory by empirically showing its role in enabling circular transitions within platform-mediated ecosystems. For managers, the results highlight that circularity cannot be achieved through isolated initiatives. Firms should strengthen innovation networks, invest in digital readiness, and adopt platform-based business models that facilitate collaboration and service-oriented offerings. Managers should also actively engage customers and partners in co-creating circular solutions, while embedding lifecycle thinking into product and platform strategies to maximize circular outcomes. For policymakers in China, the findings suggest that promoting innovation ecosystems, digital infrastructure, and collaborative platforms can accelerate circular economy adoption and lifecycle circularity. Policies that encourage cross-sector collaboration, platform development, and user participation in circular systems can enhance the effectiveness of national circular economy strategies.

6.2. Directions for Future Studies

Despite its contributions, this study has several limitations that open avenues for future research. First, the cross-sectional design limits causal inference; future studies may employ longitudinal designs to capture the dynamic evolution of circular economy adoption and lifecycle circularity. Second, the study focuses on China; comparative cross-country studies could examine how institutional and cultural differences influence the proposed relationships. Third, future research may integrate additional digital technologies or governance mechanisms to further unpack how circular strategies are operationalized across industries. Finally, qualitative or mixed-method approaches could provide deeper insights into the micro-processes through which platforms and co-creation enable lifecycle circularity.

Authors Contribution
Muhammad Sadiq: Complete the paper and the revised file.

Conflict of Interests/Disclosures
The authors declared no potential conflicts of interest regarding the article's research, authorship, and/or publication.

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Appendix

Construct	**Items**
Innovation Network Strength (INS) Adapted from: Chesbrough (2019) and Laursen and Salter (2005)	INS1: We have strong collaborative ties with external innovation partners (e.g., firms, universities).
	INS2: Our organization regularly engages in knowledge-sharing across networks.
	INS3: We are part of open innovation ecosystems that support sustainability.
	INS4: Our innovation activities are strongly supported by partnerships and alliances.
Innovation Ecosystem Dynamism (IED) Adapted from: Adner and Kapoor (2009); Jacobides et al. (2018)	IED1: Our innovation system adapts quickly to technological and environmental change.
	IED2: We collaborate in dynamic networks that co-develop sustainable solutions.
	IED3: Our organization leverages emerging technologies for CE transitions.
	IED4: The innovation environment we operate in is highly interactive and fast-changing.
	IED5: We are part of an ecosystem that fosters mutual innovation for sustainability.
Circular Economy Adoption (CEA) Adapted from: Kirchherr et al. (2017) and Lieder and Rashid (2016)	CEA1: We have adopted circular design principles in our product development.
	CEA2: Our operations include recycling, remanufacturing, and reuse strategies.
	CEA3: We prioritize minimizing waste and maximizing resource efficiency.
	CEA4: Our organization has shifted from linear to circular business models.
	CEA5: We measure success by both economic and environmental performance indicators.
Digital Transformation Readiness (DTR) Adapted from: Vial (2021); Westerman et al. (2011)	DTR1: Our leadership is committed to driving digital transformation.
	DTR2: We have the digital capabilities to adopt new platform technologies.
	DTR3: Our employees are ready and trained to support digital CE initiatives.
	DTR4: We have an organizational culture that embraces digital change.
Platform-Based Business Model Innovation (PBMI) Adapted from Lüdeke-Freund et al. (2018) and Zott and Amit (2010)	PBMI1: We have introduced new digital business models focused on circularity.
	PBMI2: Our platform offers subscription-based or product-as-a-service models.
	PBMI3: We continuously adapt our business model to support CE practices.
	PBMI4: Our platform facilitates co-creation and reuse across users.
	PBMI5: We explore novel value propositions aligned with circular economy goals.

Product Lifecycle Orientation (PLO) Adapted from Bocken et al. (2016) and Tukker (2015)	PLO1: We actively design products for durability and easy maintenance.
	PLO2: Our organization integrates reuse and remanufacturing strategies.
	PLO3: We prioritize extending the lifecycle of our products.
	PLO4: Our supply chain supports product take-back and recovery systems.
Value Co-Creation Capability (VCC) Adapted from: Prahalad and Ramaswamy (2004) and Ranjan and Read (2014)	VCC1: We involve customers in the development of circular solutions.
	VCC2: Our platform enables multi-stakeholder collaboration.
	VCC3: Value is created through shared use and mutual benefit among users.
	VCC4: We empower users to contribute to CE-related innovations.
Product Lifecycle Circularity (PLC) Adapted from (Linder & Williander, 2015; MacArthur, 2013)	PLC1: Our products are reused or refurbished multiple times.
	PLC2: Reverse logistics is integrated in our operations.
	PLC3: We systematically track the resource use and reuse across lifecycles.
	PLC4: Our business processes support material recycling and repurposing.
	PLC5: Circularity is a core KPI for evaluating lifecycle performance.
Collaborative Consumption Culture (CCC) Adapted from Botsman and Foley (2010) and Hamari et al. (2015)	CCC1: Our users prefer access over ownership of products.
	CCC2: Consumers are open to sharing or renting goods via our platform.
	CCC3: Trust among users supports collaborative consumption.
	CCC4: Our platform promotes sustainability-driven user behavior.