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Innovation for a sustainable future: Boosting circular economy practices in agriculture

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Abstract

Circular economy practices in agriculture represent a shift toward resource-efficient, sustainable farming systems that minimize waste and environmental impact. To better understand the behavioral mechanisms underlying their adoption, this study applies the Diffusion of Innovations Theory and the Theory of Planned Behavior to examine how innovation attributes and psychological constructs shape farmers' decisions. A quantitative survey was conducted among 367 farmers in the Hong River Delta. The model examines how innovation attributes such as relative advantage and compatibility influence farmers' attitudes and decision-making through the mediation of TPB constructs (attitude, subjective norms, perceived behavioral control). The results show that subjective norms have a stronger effect on sustainable practice adoption ($\beta = 0.365$, $p < 0.001$) and economic resilience ($\beta = 0.230$, $p = 0.000$) than other TPB constructs. Trialability and observability negatively influence perceived control and attitude due to limited access and visibility. The study highlights the dominant role of social factors in driving behavioral change. The integration of DOI and TPB provides a comprehensive framework for understanding farmers' adoption behavior. Social and psychological factors are central to promoting sustainable and economically resilient agriculture. Policymakers should enhance peer influence and community demonstrations while simplifying technical trials to support circular economy transitions.

Keywords: Agricultural, Circular economy, Economic resilience, Innovation, Sustainability.

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1. Introduction

Nowadays, the adoption of circular economic strategies in modern agriculture is essential to address the increasing challenges of climate change and declining resources [1]. The degradation of agriculture, water contamination, and declining biodiversity are primarily the result of traditional farming methods that follow cyclical resource utilization models. For sustainable agriculture to develop, manufacturers need to use fewer resources while minimizing waste through innovative solutions.

Despite increasing recognition of the circular economy's potential, agricultural producers show different speeds of technology uptake, which reveals essential missing information about why farmers make their choices [2]. Prior studies have concentrated on macro-level determinants, such as technology and policy advances, though micro-level determinants, especially individual and social psychological factors, have been underexplored [3].

To better understand the behavioral dynamics influencing the adoption of circular economy practices in agriculture, the Diffusion of Innovations (DOI) Theory focuses on how new practices spread within social systems based on perceived innovation attributes [4]. Meanwhile, the Theory of Planned Behavior (TPB) highlights the psychological and normative factors that influence individual decision-making [5]. While DOI effectively explains the external diffusion process, it does not account for internal cognitive reasoning, which TPB addresses through constructs such as attitude, subjective norms, and perceived behavioral control. Therefore, combining these theories provides a more comprehensive understanding of how both innovation characteristics and behavioral beliefs shape farmers' adoption intentions.

According to Ajzen's Theory of Planned Behavior, individual perceptions and decisions determine behavioral outcomes through three key steps: attitude towards behavior, subjective norms, and perceived behavioral control [6]. By merging both theories, we can better explain how innovation features work with individual mindset elements to govern behavior in circular economy adoption.

This research examines how farmers adopt circular economy practices based on their sustainability norms that develop from DOI's perceived innovation attributes [7]. This study's approach adopts the mediating role of TPB [8]. This research analyzes how different TPB aspects affect farmers' views on circular farming procedures and determines the connection between the innovation feature aspects and the performance results of interest [9]. The research focuses on examining psychological relationships between industry determinants as its central research objective, with the goal of helping policymakers and industry stakeholders encourage circular economy adoption in agriculture. Research examining farmer behaviors during circular economy adoption creates theoretical and practical contributions by showing farmer choices and developing new operational strategies that benefit farmers and environmental sustainability. This is accomplished by demonstrating how farmers behave to embrace the circular economy.

2. Literature Review

In this study, sustainable agricultural practices are understood as farming methods that optimize resource use, minimize negative environmental impacts, and maintain long-term productivity without degrading ecosystems [10]. These practices are increasingly emphasized due to growing concerns over resource depletion and environmental degradation. However, the adoption of circular production models in agriculture remains inconsistent, prompting investigations into the key drivers and barriers to implementation [11]. Addressing the inconsistent adoption of sustainable agricultural innovations requires a theoretical framework that integrates both innovation characteristics and the behavioral factors shaping farmers' decisions. The Diffusion of Innovations (DOI) focuses on how innovation attributes, such as relative advantage, compatibility, complexity, trialability, and observability, shape initial perceptions of new practices [4]. Complementarily, the Theory of Planned Behavior (TPB) accounts for psychological and social elements, including attitudes, subjective norms, and perceived behavioral control, which influence farmers' decision-making processes. Combining these theories provides a comprehensive framework to explain how external innovation features interact with internal behavioral constructs to influence circular economy adoption in agriculture [5].

2.1. Influence of Perceived Relative Advantage on Attitude, Subjective Norms, and Perceived Behavioral Control

Relative advantage stands as a vital component in the Diffusion of Innovations Theory (DOI) because it explains how new practices provide better results than traditional methods. For circular economy adoption in agriculture, relative advantage shapes farmers' attitudes toward behavioral control as well as their subjective norms that follow the central constructs of the Theory of Planned Behavior [12].

First, relative advantage positively shapes attitude, as farmers who perceive circular economy practices as offering economic, environmental, or operational benefits are more likely to develop favorable attitudes toward adoption [13]. Research suggests that perceived improvements in resource efficiency, cost savings, and soil health enhance the willingness to adopt sustainable agricultural innovations.

Second, relative advantage influences subjective norms by reinforcing the perception that influential social groups such as agricultural peers, policymakers, and consumers support circular economy practices. If farmers perceive that adopting these practices is advantageous and widely endorsed, they may feel greater normative pressure to conform [14].

Finally, relative advantage enhances perceived behavioral control, as farmers who recognize the benefits of circular economy adoption may feel more confident in their ability to implement these practices effectively [7]. If they believe these practices require fewer financial or technical barriers due to their advantages, their sense of control over adoption increases.

By linking relative advantage with TPB constructs, this framework helps explain the psychological and social factors driving the adoption of circular economy practices in agriculture.

$H_{1a.}$ When farmers perceive circular economy practices as offering clear economic and environmental benefits, they are more likely to develop a positive attitude toward adopting these practices.

$H_{1b.}$ The more advantageous circular economy practices appear to be, the stronger the social pressure farmers experience from peers and stakeholders to adopt them.

$H_{1c.}$ Farmers who recognize the clear benefits of circular economy adoption tend to feel more confident in their ability to implement these practices successfully.

2.2. Impact of Perceived Compatibility on Attitude, Subjective Norms, and Perceived Behavioral Control

Compatibility, a fundamental attribute in the Diffusion of Innovations Theory (DOI), refers to the extent to which an innovation aligns with an individual's existing values, experiences, and needs. In the context of circular economy adoption in agriculture, compatibility significantly influences attitudes, subjective norms, and perceived behavioral control, the key constructs of the Theory of Planned Behavior (TPB).

First, compatibility positively shapes attitudes, as farmers are more likely to develop a favorable perception of circular economy practices if they align with their current farming methods, cultural beliefs, and economic goals [15]. When sustainable agricultural innovations fit well with traditional practices or existing resource management strategies, farmers perceive them as more acceptable and less disruptive, reinforcing positive attitudes toward adoption [16].

Second, compatibility influences subjective norms, as farmers often look to peers, industry networks, and agricultural policymakers for guidance [17]. If circular economy practices align with established norms in the farming community, social acceptance increases, creating stronger normative pressure to adopt these innovations. The perceived support from family, agricultural cooperatives, or consumer expectations further reinforces the likelihood of adoption [18].

Finally, compatibility enhances perceived behavioral control, as farmers feel more capable of implementing circular economy practices when they fit well with their existing knowledge, infrastructure, and resources. A higher level of compatibility reduces perceived barriers [13] such as technical complexity or additional financial investments, making farmers feel more confident in their ability to adopt and sustain these practices.

$H_{2a.}$ Farmers are more inclined to view circular economy practices positively when these practices align well with their existing farming routines and values.

$H_{2b.}$ The better circular practices fit with farmers' current systems and cultural expectations, the more likely they are to sense encouragement from their social circles to adopt them.

$H_{2c.}$ When circular economy innovations feel familiar and easy to integrate, farmers are more likely to believe they can adopt them without major difficulties.

2.3. Effect of Perceived Complexity on Attitude, Subjective Norms, And Perceived Behavioral Control

Complexity is a fundamental concept in the Diffusion of Innovations Theory (DOI), describing the extent to which an innovation is perceived as difficult to understand and implement. Higher complexity often acts as a barrier to adoption, particularly in agricultural settings where traditional practices are deeply embedded. In the context of circular economy adoption in agriculture, complexity interacts with attitude, subjective norms, and perceived behavioral control, as defined in the Theory of Planned Behavior (TPB), to shape farmers' decision-making processes [18].

A significant challenge is that many circular economy innovations require advanced knowledge, specialized equipment, or changes in long-standing practices, which can lead to negative attitudes toward adoption [19]. Studies suggest that when farmers perceive these innovations as overly complicated or impractical, they are less likely to view them favorably. Moreover, subjective norms may exert a weaker influence if farmers see complexity as a hindrance [20]. Even if external stakeholders promote sustainable practices, adoption remains limited when perceived difficulty outweighs perceived benefits [7]. Additionally, perceived behavioral control declines as complexity increases, making farmers feel incapable of integrating new practices due to knowledge gaps, financial constraints, or technical difficulties [18]. While DOI emphasizes innovation attributes, it often underestimates these psychological barriers, underscoring the importance of TPB in explaining why complexity inhibits adoption despite potential long-term benefits [21].

$H_{3a.}$ When circular economy practices are perceived as overly complicated or difficult to apply, farmers tend to hold more negative attitudes toward them.

$H_{3b.}$ Greater complexity reduces farmers' confidence in their ability to adopt new practices effectively.

$H_{3c.}$ Even with social encouragement, farmers may feel discouraged from adopting complex innovations due to technical or financial concerns.

2.4. Role of Perceived Trialability in Shaping Attitude, Subjective Norms, and Perceived Behavioral Control

Trialability, a key attribute in the Diffusion of Innovations Theory (DOI), refers to the extent to which an innovation can be experimented with before full-scale adoption. In the context of circular economy adoption in agriculture, trialability plays a crucial role in shaping attitudes, subjective norms, and perceived behavioral control, which are core constructs of the Theory of Planned Behavior [22].

First, trialability positively influences attitude by reducing uncertainty and allowing farmers to assess the benefits and feasibility of circular economy practices before making long-term commitments [22]. Research suggests that when farmers can test sustainable agricultural innovations such as organic composting, regenerative soil techniques, or water recycling systems, they are more likely to develop favorable attitudes toward their adoption. The ability to observe direct outcomes through small-scale trials fosters confidence in the innovation's effectiveness [23].

Second, trialability enhances subjective norms, as farmers who successfully experiment with circular economy practices can share their experiences with peers, extension officers, or agricultural cooperatives [22]. If early adopters can demonstrate positive results, it strengthens the normative influence on other farmers, increasing social pressure to adopt. The ability to trial new practices not only benefits individual farmers by reducing uncertainty but also accelerates the wider adoption of sustainable agricultural methods within farming communities by fostering shared knowledge and practical demonstrations [24].

Finally, trialability strengthens perceived behavioral control, as hands-on experience reduces perceived risks and barriers associated with implementation [25]. Farmers who engage in small-scale trials gain practical knowledge, which enhances their sense of control over adoption. The ability to test an innovation before committing to large-scale changes reduces concerns related to financial risks, technical complexity, or operational adjustments, making adoption more feasible [26]. While DOI highlights the importance of trialability in promoting adoption, the TPB further explains how it interacts with psychological and social factors, reinforcing the decision-making process toward circular economy practices in agriculture.

$H_{4a.}$ Farmers who are permitted to experiment with circular economy techniques on a trial basis are more likely to develop a favorable attitude toward them.

$H_{4b.}$ The opportunity to test practices before fully committing helps farmers feel more capable and in control of the adoption process.

$H_{4c.}$ Visible successful trials boost farmers' social motivation to adopt.

2.5. Contribution of Perceived Observability to Attitude, Subjective Norms, and Perceived Behavioral Control

Observability refers to the extent to which the benefits and outcomes of an innovation are visible to others, influencing how quickly and widely it is adopted [27]. In the context of circular economy adoption in agriculture, observability plays a crucial role in shaping attitudes, subjective norms, and perceived behavioral control, which are core constructs of the Theory of Planned Behavior.

First, observability positively influences attitudes, as farmers who witness the success of circular economy practices on other farms are more likely to develop favorable perceptions toward adoption [20]. Seeing tangible improvements such as increased soil fertility, reduced input costs, or higher crop yields can reinforce the perceived benefits of sustainable agricultural practices [7]. Empirical studies suggest that when the positive effects of innovations are highly visible, individuals are more inclined to adopt them due to reduced uncertainty [28].

Second, observability strengthens subjective norms, as visible success stories create social proof that reinforces collective expectations within farming communities [29]. When farmers observe their peers, local leaders, or agricultural cooperatives adopting circular economy practices with measurable success, the perceived social pressure to conform increases. The more frequently an innovation is seen in use, the stronger the normative influence, which can accelerate widespread adoption [24].

Finally, observability enhances perceived behavioral control, as clear demonstrations of successful implementation reduce perceived complexity and uncertainty [20]. Farmers who see others effectively using circular economy practices gain confidence in their own ability to adopt them. Observability provides concrete examples of best practices, offering learning opportunities that lower perceived risks and improve the perceived ease of transition [25].

By integrating insights from the Diffusion of Innovations Theory (DOI) and the Theory of Planned Behavior (TPB), this relationship underscores how the visibility of benefits can drive both psychological and social motivations for circular economy adoption in agriculture.

$H_{5a.}$ Farmers who can clearly observe the benefits of circular practices in others' fields are more inclined to develop positive attitudes.

$H_{5b.}$ Seeing tangible outcomes helps reduce uncertainty and improves farmers' belief that they can implement the practices effectively.

$H_{5c.}$ Widespread visibility of successful adoption enhances social norms, making farmers feel greater peer pressure to adopt similar methods.

2.6. Attitudes, Subjective Norms, and Perceived Behavioral Control Drive the Adoption of Sustainable Farming Practices or the Economic Resilience of Farmers

The Theory of Planned Behavior (TPB) provides a robust framework for understanding how psychological and social factors drive the adoption of sustainable farming practices and enhance the economic resilience of farmers [30]. TPB posits that three key constructs: attitude, subjective norms, and perceived behavioral control shape an individual's intention and subsequent behavior.

First, the attitude toward sustainable farming practices plays a crucial role in adoption decisions. Farmers who perceive these practices as beneficial in terms of environmental sustainability, cost efficiency, and long-term productivity are more likely to embrace them [30]. Positive attitudes are influenced by perceived benefits such as reduced dependency on chemical inputs, improved soil health, and enhanced economic stability through resource efficiency [13]. Studies suggest that when farmers recognize these advantages, they are more inclined to integrate circular economy principles into their agricultural systems [31].

Second, subjective norms significantly impact farmers' willingness to adopt sustainable practices. Social influences from peers, agricultural cooperatives, extension services, and consumer demand create normative pressures that encourage behavioral change [14]. When sustainable farming practices become widely accepted within a community, farmers experience stronger social expectations to conform, which increases the likelihood of adoption [32]. Additionally, government policies and incentives further reinforce these norms, fostering an environment conducive to the adoption of a circular economy [33].

Finally, perceived behavioral control determines whether farmers feel capable of implementing sustainable practices [21]. Access to knowledge, financial resources, and technical support enhances their confidence in adoption. Conversely, barriers such as high initial investment costs, lack of training, or uncertain market demand may limit perceived control and reduce adoption rates [7]. Strengthening support systems, providing financial incentives, and simplifying technological integration can improve perceived behavioral control and drive economic resilience [34].

$H_{6.}$ Farmers who hold a positive attitude toward circular economy practices are more likely to feel capable and in control when it comes to adopting these practices.

$H_{7.}$ Farmers who feel supported or encouraged by their social circles including peers, cooperatives, or policymakers are more likely to believe they can successfully adopt circular economy practices.

$H_{8a.}$ A favorable attitude toward circular practices increases the likelihood that farmers will adopt sustainable farming methods.

$H_{8b.}$ Positive attitudes also contribute to farmers' long-term economic resilience by encouraging investment in sustainable innovations.

$H_{9a.}$ When farmers feel confident in their ability to apply circular economy practices, they are more likely to implement sustainable farming techniques.

$H_{9b.}$ Strong perceived control also supports greater economic stability by enabling farmers to manage new practices effectively.

$H_{10a.}$ Social expectations and peer influence play a central role in motivating farmers to adopt sustainable farming practices.

$H_{10b.}$ Farmers who sense strong social support are more likely to experience improved economic resilience through collective adoption and knowledge sharing.

By integrating the Theory of Planned Behavior (TPB) with circular economy adoption in Figure 1, this framework highlights how psychological, social, and resource-based factors collectively influence farmers' decisions and long-term sustainability.

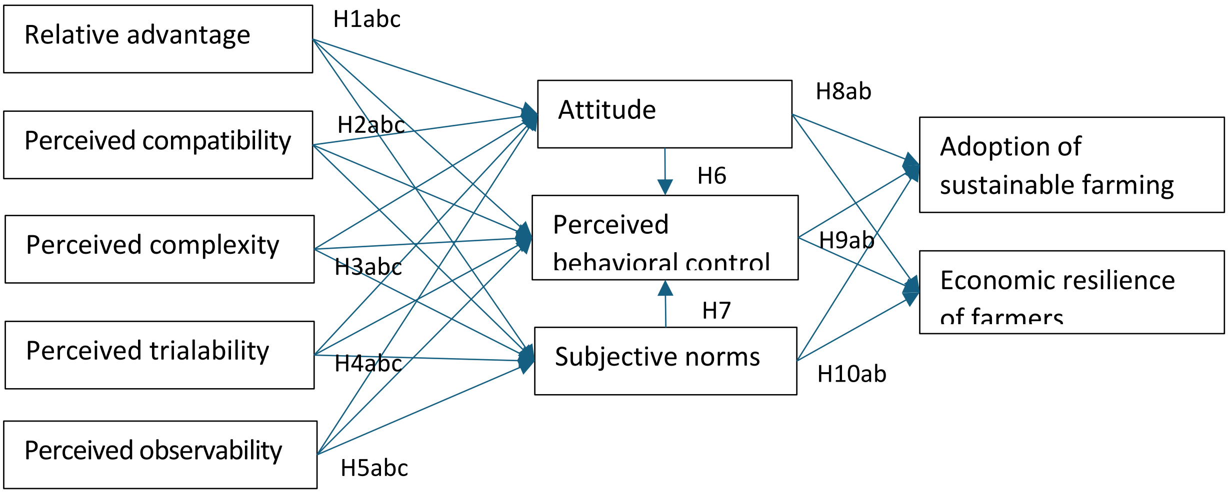

Figure 1.
Conceptual framework integrating DOI and TPB.

3. Methodology

3.1. Research Design and Measurement

This study employs a mixed-methods approach. In the initial phase, a comprehensive review and critical analysis of previous studies were conducted to identify and refine measurement items for each construct. A pilot test was then conducted with 30 faculty members specializing in economics and business to evaluate the reliability and validity of the measurement scales. The assessment ensured both discriminant and convergent validity, with key reliability indicators including Composite Reliability (CR) and Cronbach's Alpha exceeding 0.7, while the Average Variance Extracted (AVE) for each construct met the threshold of 0.5 or higher.

Following the qualitative phase, a quantitative analysis was performed to examine the factors influencing the adoption of the circular economy (CE) in agriculture. The research model was developed by integrating the Diffusion of Innovations Theory (DOI) and the Theory of Planned Behavior (TPB).

This study conceptualizes the innovation attributes from DOI including relative advantage, compatibility, complexity, trialability, and observability and examines their influence on farmers' perceptions of economic efficiency and environmental sustainability. The TPB constructs (attitude, subjective norms, and perceived behavioral control) are incorporated as mediators to better explain the adoption process. In addition, the demographic characteristics of the sample can determine the research context and characteristics of this discussion [7].

3.2. Sampling Procedure

Understanding the factors influencing the adoption of circular economy practices in agriculture is essential for developing effective policies and interventions. This study applies a quantitative approach using Partial Least Squares Structural Equation Modeling (PLS-SEM), a widely recognized method for analyzing complex models with latent variables.

The sample was drawn from four major agricultural provinces in the Hong River Delta: Thai Binh, Nam Dinh, Ha Nam, and Ninh Binh, with an equal distribution of 25% per province. To ensure an adequate sample size for PLS-SEM, the 10-times rule was applied [34]. Given that the model includes a latent variable (BC) with the highest number of incoming paths (7) and each construct is measured by at least four indicators, the minimum required sample size was determined to be 70 responses [35]. However, simulation-based research indicates that SEM models with multiple latent variables and indirect effects typically require a larger sample size, with at least 300 responses recommended for stable parameter estimation [36]. In this study, the initial target sample size was set at 500 respondents. Ultimately, 367 valid responses were collected, resulting in a response rate of 73.4%. This final sample size ensures sufficient statistical power and model reliability for robust hypothesis testing. Digital surveys via Google Drive facilitated data collection from June 2023 to June 2024, with participation strictly voluntary.

3.3. Data Analysis

To ensure the reliability of the measurement instruments, the study conducted a comprehensive assessment using Cronbach's Alpha and Composite Reliability (CR) to evaluate internal consistency. Additionally, discriminant and convergent validity were examined within the PLS-SEM framework, utilizing Average Variance Extracted (AVE) as a key criterion to confirm construct validity. These steps strengthened the robustness of the dataset and ensured the accuracy of the measurement model.

For hypothesis testing and structural analysis, the study employed SmartPLS version 4.0.9.2, a widely recognized tool in quantitative research due to its flexibility in handling latent constructs and non-normal data distributions [35]. The PLS algorithm was applied to estimate loading factors, weights, and path coefficients. Furthermore, to assess the significance of the proposed hypotheses, bootstrapping with 5000 resamples was conducted. The analysis also included Variance Inflation Factor (VIF) calculations to check for potential multicollinearity issues within the structural model.

4. Results

4.1. Demographic Characteristics

Table 1.
Demographic characteristics of survey respondents.

Demographic variable	Category	Frequency	Percentage (%)
Gender			
	Female	164	44.687
	Male	203	55.313
Age group			
	18 - 30	76	20.708
	31 - 40	153	41.689
	41 - 50	46	12.534
	51 - 60	81	22.071
	Above 60	11	2.997
Membership in agricultural cooperatives			
	Yes	127	34.605
	No	240	65.395
Land ownership status			
	Owned land	284	77.384
	Rented land	22	5.995
	Both owned and rented land	61	16.621

Table 1 presents the demographic characteristics of the survey respondents. The sample consists of 55.31% male farmers (n=203) and 44.69% female farmers (n=164), indicating a relatively balanced gender representation. This distribution helps assess potential gender-based differences in adopting circular economy practices. The largest proportion of respondents falls within the 31-40 age group (41.69%), followed by 51-60 (22.07%) and 18-30 (20.71%). The lower representation of farmers above 60 (2.99%) suggests that older individuals may be less engaged in agricultural innovation studies. A significant 65.40% of farmers are not members of cooperatives, while 34.61% are members. This indicates that many farmers operate independently, which may influence their access to financial and technical support for sustainable farming.

Most respondents (77.38%) own their farmland, while 16.62% have both owned and rented land, and 5.99% rely solely on rented land. Ownership status can impact investment decisions in sustainable farming practices. The combination of population factors determines how farmers adopt circular economy principles.

4.2. Evaluation of the External Structure's Validity

Table 2.
Reliability and validity of measurement constructs.

Items	Measurements (Cronbach's alpha)	Outer loading	VIF
RA	Relative advantage (0.879)		
RA1	Farmers' perception of circular economy principles results in economic and environmental benefits, which drives their positive attitude toward circular practices [2].	0.859	2.352
RA2	Farmers implement circular economy practices under social expectations from their peers, policymakers, and consumer base [14].	0.888	2.591
RA3	Farmers perceive circular economy approaches as methods to make resources more efficient and decrease barriers, which therefore boosts their willingness to adopt these practices [7].	0.887	2.536
RA4	Farmers increase their willingness to adopt circular economy practices after understanding that the practical benefits surpass those of traditional practices[12].	0.790	1.830
PC	Perceived compatibility (0.888)		
PC1	Farmers accept circular economy practices better when these models complement their existing agricultural practices alongside their economic objectives [15].	0.869	2.386
PC2	Farmers experience stronger social acceptance of circular economy practices when these align with community norms and industry expectations [17].	0.862	2.356
PC3	Farmers feel more capable of adopting circular economy practices when they fit well with existing knowledge, infrastructure, and resources [13].	0.855	2.188
PC4	Farmers are likely to accept circular economy practices if they easily integrate with their conventional farming systems [16].	0.875	2.457
CX	Perceived complexity (0.882)		
CX1	Farmers view the implementation of a circular economy as challenging because they require sophisticated knowledge along with specialized equipment to succeed [19].	0.875	2.463
CX2	Farmers are less likely to adopt circular economy practices when they perceive them as impractical or overly complicated [20].	0.866	2.407
CX3	Farmers experience weaker social pressure to adopt circular economy practices when complexity is perceived as a major hindrance [7].	0.826	1.965
CX4	Farmers feel less confident in adopting circular economy practices due to knowledge gaps, financial constraints, or technical difficulties [18].	0.870	2.327
TR	Perceived trialability (0.846)		
TR1	Farmers develop a more favorable attitude toward circular economy practices when they can test them on a small scale before full adoption [22].	0.844	1.949
TR2	Farmers are more likely to adopt circular economy practices when they see successful trials conducted by their peers or agricultural cooperatives [24].	0.836	2.029
TR3	Farmers feel more confident in adopting circular economy practices when they have hands-on experience, reducing perceived risks [25].	0.863	2.356
TR4	Farmers find circular economy practices more achievable when they experience trial periods to assess financial as well as operational outcomes [26].	0.763	1.545
OB	Perceived observability (0.881)		
OB1	Farmers will have a better attitude toward circular economy practices after witnessing successful implementation efforts on different farms [20].	0.842	2.194
OB2	Farmers experience stronger social pressure to adopt circular economy practices when they observe widespread adoption within their community [29].	0.867	2.211
OB3	Farmers gain confidence in adopting circular economy practices when they observe clear demonstrations of successful implementation [20].	0.857	2.141
OB4	Farmers will see lower risks and greater practicality for circular economy practices after observing concrete advantages achieved by their fellow farmers [25].	0.869	2.435
AT	Attitude toward sustainable agricultural (0.885)		
AT1	Farmers believe that adopting sustainable agricultural practices improves long-term economic and environmental outcomes [2].	0.857	2.213
AT2	Farmers view sustainable agricultural methods as compatible with their current farming techniques and tackle available resources [16].	0.855	2.220
AT3	Farmers accept sustainable farming methods since these measures help decrease environmental threats and reinforce soil quality positively [9].	0.857	2.238

AT4	Farmers have a favorable perception of sustainable agricultural innovations that enhance productivity while reducing waste [28].	0.879	2.485
SN	Subjective norms (0.910)		
SN1	Farmers feel encouraged to adopt circular economy practices when peers and agricultural cooperatives support them [29].	0.845	2.169
SN2	Farmers believe that industry leaders and policymakers strongly expect them to implement circular economy approaches [24].	0.887	2.801
SN3	Farmer acceptance of circular economy practices increases through their observation of successful implementation by respected farmers and early adopters [20].	0.878	2.668
SN4	Farmers base their decisions to implement circular economy practices on both consumer demands in the market and current market trends [22].	0.856	2.190
BC	Perceived behavioral control (0.889)		
BC1	Farmer confidence in implementing circular economy practices depends on having sufficient knowledge and access to training [7].	0.891	2.778
BC2	Farmers believe that financial support and subsidies make it easier for them to implement circular economy solutions [18].	0.888	2.677
BC3	Farmers perceive fewer barriers to adopting circular economy practices when they have adequate infrastructure and equipment [20].	0.891	2.866
BC4	Farmers' integration of circular economy practices heavily depends on system implementation convenience and essential technical standards [25].	0.880	2.650
AP	Adoption of sustainable farming practices (0.899)		
AP1	Farms can optimize their resource management through waste minimization practices and circular economy approaches [31].	0.870	2.400
AP2	Farmers apply sustainable farming methods that improve their land conditions and enhance soil health and biodiversity [30].	0.883	2.594
AP3	Farmers fulfill their daily farming tasks as part of their implementation of environmentally friendly practices [32].	0.866	2.329
AP4	Farmers choose sustainable practices instead of conventional methods when making important farming decisions [7].	0.885	2.787
ER	Economic resilience of farmers (0.890)		
ER1	Farmers experience improved financial stability after adopting circular economy practices [7].	0.859	2.243
ER2	Farms view the adoption of circular economy principles as a method to lower expenditure while strengthening financial performance [31].	0.878	2.581
ER3	Farmer financial stability increases because sustainable farming generates new market opportunities [30].	0.856	2.236
ER4	Farmers recognize sustainable agricultural innovations as essential tools that build their businesses' resilience to future challenges [32].	0.878	2.572

Table 2 assesses measurement model reliability and validity through Cronbach’s Alpha, Outer Loadings, and Variance Inflation Factor (VIF). According to Hair et al. [35] , Cronbach’s Alpha measurement must reach at least 0.70 to verify internal consistency reliability. The chosen threshold demonstrates that all measuring variables within the constructs evaluate the same core concept effectively. Weak reliability indicators may exist when values drop below 0.70, which calls for reviewing or updating specific items. The validation process maintains essential standards regarding measurement precision as well as construct reliability.

In addition to reliability, indicator reliability is assessed through outer loadings. Cronbach’s Alpha should be ≥ 0.70 to ensure internal consistency reliability, as suggested by [35]. The measurement model can retain a loading that ranges from 0.4 to 0.708 when the construct’s average variance extracted exceeds 0.50. The removal process starts when any loading drops below 0.4, since weak contributions warrant elimination. Achieving good convergent validity in a measurement model requires most indicators to display strong loadings.

Moreover, the variance inflation factor (VIF) is the index used to determine multicollinearity so that indicators remain independent from one another. VIF values should remain ≤ 5.00 to avoid multicollinearity issues, as recommended by Hair et al. [35]. Preferably, a VIF value below 3.00 indicates the absence of collinearity problems, while values between 3.00 and 5.00 demonstrate moderate acceptable collinearity. No correction should be made for variables exceeding a VIF of 5.00, so removing redundant indicators would be necessary. The measurement model functions properly as a reliable and valid approach to conduct structural analysis when all constructs reach their defined thresholds of Cronbach’s Alpha, Outer Loadings, and VIF.

4.3. Analysis Results of the Framework Model's Convergent and Discriminant Validity

Table 3.
Discriminant validity (Fornell–Larcker Criterion).

	CR	AVE	AP	AT	BC	CX	ER	OB	PC	RA	SN	TR
AP	0.900	0.767	0.876									
AT	0.885	0.743	0.420	0.862								
BC	0.891	0.751	0.460	0.488	0.867							
CX	0.884	0.739	0.342	0.344	0.369	0.860						
ER	0.891	0.753	0.327	0.342	0.355	0.224	0.868					
OB	0.886	0.737	0.000	-0.241	-0.254	-0.113	-0.085	0.859				
PC	0.888	0.749	0.280	0.386	0.419	0.382	0.194	-0.180	0.865			
RA	0.894	0.734	0.331	0.388	0.361	0.415	0.261	-0.093	0.454	0.857		
SN	0.911	0.788	0.520	0.354	0.405	0.263	0.363	0.192	0.245	0.271	0.888	
TR	0.849	0.684	-0.239	-0.357	-0.326	-0.236	-0.159	0.188	-0.236	-0.150	-0.232	0.827

Note: Perceived relative advantage (RA), Perceived compatibility (PC), Perceived complexity (CX), Perceived trialability (TR), Perceived observability (OB), Attitude toward sustainable agricultural practices (AT), Subjective norms (SN), Perceived behavioral control (BC), Adoption of sustainable farming practices (AP), Economic resilience of farmers (ER)

Table 3 presents the discriminant validity assessment using the Fornell and Larcker criterion, which ensures that each construct in the model is empirically distinct from the others. This is crucial in validating the measurement model in PLS-SEM (Partial Least Squares Structural Equation Modeling). Discriminant validity is established when the square root of the average variance extracted (AVE) for each construct is greater than its correlations with other constructs. The table also includes composite reliability (CR) and AVE values, which help confirm internal consistency and convergent validity.

The CR values in Table 3 range from 0.849 to 0.911, all exceeding the recommended threshold of 0.70 [35]. This indicates strong internal consistency reliability for all constructs, meaning that the measurement items within each construct reliably represent the same underlying concept. Furthermore, the AVE values range from 0.684 to 0.788, all surpassing the acceptable threshold of 0.50, confirming that each construct captures sufficient variance from its indicators. These results suggest that the model demonstrates adequate reliability and convergent validity.

For discriminant validity evaluation, the diagonal values in Table 3 represent the square root of AVE, and they should be higher than the off-diagonal correlation values. The results indicate that most constructs meet this criterion, confirming that they are conceptually distinct [37].

Overall, the measurement model satisfies the requirements for reliability, convergent validity, and discriminant validity. However, to further validate these findings, researchers could perform additional tests such as Heterotrait-Monotrait (HTMT) ratio analysis to ensure that there are no severe issues with discriminant validity.

4.4. Analysis of the Inner Model's Validity

Table 4.
Findings of the proposed structural model analysis.

Hypothesis	Relationship	Estimated effect	Standard error	Test statistic (t)	P values
H1.a	RA -> AT	0.216	0.053	4.078	0.000
H1.b	RA -> BC	0.071	0.049	1.448	0.148
H1.c	RA -> SN	0.153	0.058	2.624	0.009
H2.a	PC -> AT	0.162	0.052	3.112	0.002
H2.b	PC -> BC	0.151	0.051	2.988	0.003
H2.c	PC -> SN	0.128	0.057	2.252	0.024
H3.a	CX -> AT	0.123	0.054	2.269	0.023
H3.b	CX -> BC	0.101	0.049	2.060	0.039
H3.c	CX -> SN	0.135	0.062	2.187	0.029
H4.a	OB -> AT	-0.134	0.042	3.177	0.001
H4.b	OB -> BC	-0.199	0.048	4.148	0.000
H4.c	OB -> SN	0.282	0.064	4.381	0.000
H5.a	TR -> AT	-0.232	0.055	4.250	0.000
H5.b	TR -> BC	-0.086	0.050	1.706	0.088
H5.c	TR -> SN	-0.201	0.060	3.333	0.001
H6	AT -> BC	0.192	0.057	3.366	0.001
H7	SN -> BC	0.272	0.056	4.885	0.000
H8.a	AT -> AP	0.182	0.061	2.965	0.003
H8.b	AT -> ER	0.174	0.063	2.766	0.006
H9.a	BC -> AP	0.223	0.063	3.555	0.000
H9.b	BC -> ER	0.177	0.062	2.846	0.004
H10.a	SN -> AP	0.365	0.063	5.781	0.000
H10.b	SN -> ER	0.230	0.064	3.590	0.000

Note: Perceived relative advantage (RA), Perceived compatibility (PC), Perceived complexity (CX), Perceived trialability (TR), Perceived observability (OB), Attitude toward sustainable agricultural practices (AT), Subjective norms (SN), Perceived behavioral control (BC), Adoption of sustainable farming practices (AP), Economic resilience of farmers (ER).

The analysis shows in Table 4 how diffusion of innovations theory and theory of planned behavior influence farmers' adoption of circular economy practices, with a stronger preference for sustainable farming practices over economic resilience.

The results indicate that several hypotheses show statistically significant positive effects ($p < 0.05$), confirming their role in influencing farmers' adoption of circular economy practices (H1a, H1b, H2a, H2b, H2c, H7). Relative advantage (RA) positively affects attitude ($\beta = 0.216$, $p < 0.001$) and subjective norms ($\beta = 0.153$, $p = 0.009$), suggesting that when farmers perceive circular economy practices as beneficial, they develop a more favorable attitude and experience greater social pressure to adopt them [13]. Similarly, perceived compatibility significantly enhances AT ($\beta = 0.162$, $p = 0.002$), SN ($\beta = 0.128$, $p = 0.024$), and perceived behavioral control ($\beta = 0.151$, $p = 0.003$), highlighting that when these practices align with existing farming methods, farmers feel more confident in their ability to implement them. Subjective norms also exhibit a strong positive impact on AP ($\beta = 0.365$, $p < 0.001$), reinforcing the importance of social influence in shaping sustainable farming adoption [7]. Conversely, some constructs have negative path coefficients (-), indicating a deterrent effect on adoption (H5a, H5c, H6a, H6b). Perceived observability negatively influences AT ($\beta = -0.134$, $p = 0.001$) and BC ($\beta = -0.199$, $p < 0.001$), implying that when farmers struggle to observe the tangible benefits of circular economy practices, their confidence in adopting them decreases [25]. Similarly, perceived trialability negatively affects AT ($\beta = -0.232$, $p < 0.001$) and SN ($\beta = -0.201$, $p = 0.001$), suggesting that if farmers perceive these innovations as requiring excessive experimentation or adjustment, they may be discouraged from adoption. These findings indicate that while the ability to trial an innovation is generally beneficial, excessive complexity or uncertainty during trials can create resistance [38]. Finally, a few hypotheses do not exhibit statistically significant effects ($p > 0.05$), suggesting that certain DOI constructs may not strongly influence farmers' decision-making in this context (H3b, H5b). For instance, the relationship between perceived complexity and SN ($\beta = 0.041$, $p = 0.217$) is not significant, indicating that complexity does not necessarily impact the perceived social pressure to adopt circular economy practices. Additionally, the effect of OB on SN ($\beta = -0.097$, $p = 0.086$) does not reach statistical significance, suggesting that while observability may influence attitude and perceived control, it does not significantly shape social norms within farming communities. These non-significant findings highlight areas where further investigation may be needed to understand the context-specific barriers to adoption.

The TPB constructs attitude, subjective norms, and perceived behavioral control serve as key mediators linking DOI attributes to farmers' behavioral outcomes. SN strongly influences BC ($\beta = 0.272$, $p < 0.001$), indicating that social pressure from peers, policymakers, and consumers plays a crucial role in shaping farmers' confidence in adopting circular economy practices [39]. AT and BC also positively influence AP and ER, with AT → AP ($\beta = 0.182$, $p = 0.003$), AT → ER ($\beta = 0.174$, $p = 0.006$), BC → AP ($\beta = 0.223$, $p < 0.001$), and BC → ER ($\beta = 0.177$, $p = 0.004$), highlighting that farmers with positive attitudes and strong perceived control are more likely to adopt sustainable practices and experience economic benefits. Moreover, SN exhibits the strongest effect on AP ($\beta = 0.365$, $p < 0.001$), suggesting that subjective norms are a key driver in sustainable farming adoption [18]. This implies that farmers are highly influenced by their social environment when making decisions about circular economy practices.

The results show that farmers prioritize adopting sustainable farming practices (AP) over economic resilience (ER). Path coefficients from SN, BC, and AT to AP are consistently higher than those to ER, indicating that farmers are more focused on integrating sustainable practices due to social expectations, perceived environmental responsibility, and the practical feasibility of circular economy techniques.

To understand the details of the intermediate steps in the analysis, Table 5 presents the results of how innovation attributes influence behavioral outcomes. This table highlights the combined impact of DOI and TPB in shaping farmers' decision-making.

Table 5.
Indirect effects of innovation attributes via TPB constructs.

Total indirect effects	Path coefficients	Sample mean	Standard deviation	T statistics	P values
OB -> AT -> BC -> AP	-0.006	-0.006	0.003	1.770	0.077
PC -> AT -> BC	0.031	0.031	0.014	2.203	0.028
OB -> AT -> BC -> ER	-0.005	-0.005	0.003	1.532	0.126
CX -> AT -> AP	0.022	0.023	0.014	1.618	0.106
CX -> AT -> ER	0.021	0.021	0.013	1.674	0.094
AT -> BC -> AP	0.043	0.042	0.018	2.408	0.016
PC -> SN -> BC -> ER	0.006	0.006	0.004	1.683	0.092
PC -> SN -> BC -> AP	0.008	0.008	0.004	1.778	0.075
CX -> BC -> AP	0.023	0.023	0.014	1.626	0.104
RA -> AT -> ER	0.038	0.038	0.018	2.080	0.038
RA -> AT -> AP	0.039	0.039	0.016	2.408	0.016
CX -> BC -> ER	0.018	0.018	0.012	1.525	0.127
PC -> BC -> AP	0.034	0.034	0.015	2.254	0.024
OB -> SN -> BC	0.077	0.076	0.022	3.568	0.000
RA -> AT -> BC -> ER	0.007	0.007	0.004	1.735	0.083
RA -> AT -> BC -> AP	0.009	0.009	0.005	1.923	0.055
OB -> SN -> BC -> ER	0.014	0.014	0.006	2.269	0.023
OB -> SN -> BC -> AP	0.017	0.017	0.006	2.690	0.007
TR -> SN -> BC	-0.055	-0.055	0.020	2.754	0.006
CX -> AT -> BC -> AP	0.005	0.005	0.003	1.534	0.125
TR -> SN -> AP	-0.073	-0.073	0.025	2.882	0.004
TR -> BC -> AP	-0.019	-0.019	0.013	1.482	0.138
SN -> BC -> ER	0.048	0.048	0.019	2.550	0.011
TR -> SN -> ER	-0.046	-0.046	0.020	2.316	0.021
TR -> BC -> ER	-0.015	-0.015	0.011	1.408	0.159
TR -> AT -> BC	-0.045	-0.044	0.017	2.687	0.007
CX -> AT -> BC -> ER	0.004	0.004	0.003	1.429	0.153
TR -> AT -> BC -> ER	-0.008	-0.008	0.004	1.813	0.070
TR -> AT -> BC -> AP	-0.010	-0.010	0.005	2.086	0.037
SN -> BC -> AP	0.061	0.060	0.020	2.998	0.003
RA -> SN -> BC -> AP	0.009	0.009	0.005	1.993	0.046
CX -> SN -> BC	0.037	0.037	0.019	1.944	0.052
RA -> SN -> BC	0.042	0.042	0.018	2.266	0.024
RA -> SN -> BC -> ER	0.007	0.007	0.004	1.834	0.067
OB -> AT -> BC	-0.026	-0.026	0.012	2.079	0.038
TR -> SN -> BC -> AP	-0.012	-0.012	0.006	2.130	0.033
TR -> SN -> BC -> ER	-0.010	-0.010	0.005	1.862	0.063
CX -> SN -> BC -> ER	0.006	0.007	0.004	1.487	0.137
CX -> SN -> BC -> AP	0.008	0.008	0.005	1.746	0.081
OB -> BC -> AP	-0.044	-0.044	0.016	2.806	0.005
TR -> AT -> AP	-0.042	-0.043	0.018	2.322	0.020
TR -> AT -> ER	-0.040	-0.040	0.017	2.321	0.020
PC -> SN -> BC	0.035	0.034	0.017	2.098	0.036
PC -> BC -> ER	0.027	0.027	0.013	2.086	0.037
OB -> BC -> ER	-0.035	-0.035	0.015	2.325	0.020
OB -> SN -> ER	0.065	0.065	0.023	2.768	0.006
PC -> SN -> AP	0.047	0.046	0.022	2.108	0.035

OB -> SN -> AP	0.103	0.104	0.033	3.165	0.002
PC -> SN -> ER	0.029	0.029	0.016	1.849	0.064
OB -> AT -> ER	-0.023	-0.024	0.012	1.983	0.047
PC -> AT -> AP	0.030	0.030	0.015	1.966	0.049
PC -> AT -> BC -> AP	0.007	0.007	0.004	1.860	0.063
AT -> BC -> ER	0.034	0.034	0.017	2.041	0.041
OB -> AT -> AP	-0.024	-0.024	0.011	2.176	0.030
RA -> BC -> AP	0.016	0.016	0.012	1.277	0.202
CX -> SN -> AP	0.049	0.050	0.025	1.958	0.050
PC -> AT -> ER	0.028	0.028	0.014	2.029	0.043
PC -> AT -> BC -> ER	0.006	0.006	0.003	1.635	0.102
RA -> BC -> ER	0.013	0.013	0.010	1.214	0.225
CX -> SN -> ER	0.031	0.031	0.017	1.865	0.062
CX -> AT -> BC	0.024	0.023	0.013	1.794	0.073
RA -> AT -> BC	0.041	0.042	0.018	2.365	0.018
RA -> SN -> ER	0.035	0.036	0.019	1.871	0.061
RA -> SN -> AP	0.056	0.057	0.024	2.283	0.022

Note: Perceived relative advantage (RA), Perceived compatibility (PC), Perceived complexity (CX), Perceived trialability (TR), Perceived observability (OB), Attitude toward sustainable agricultural practices (AT), Subjective norms (SN), Perceived behavioral control (BC), Adoption of sustainable farming practices (AP), Economic resilience of farmers (ER).

The analysis results from Table 4 and Table 5 display construct relationships through the Figure 2 path diagram. The visual representation demonstrates all direct and indirect relationships among DOI constructs in addition to TPB mediators and outcome variables. This visualization is particularly valuable for policymakers, researchers, and practitioners. Professionals can utilize this visual model as a reference tool to analyze model relationships and develop interventions that boost circular economy practice adoption in agricultural sectors.

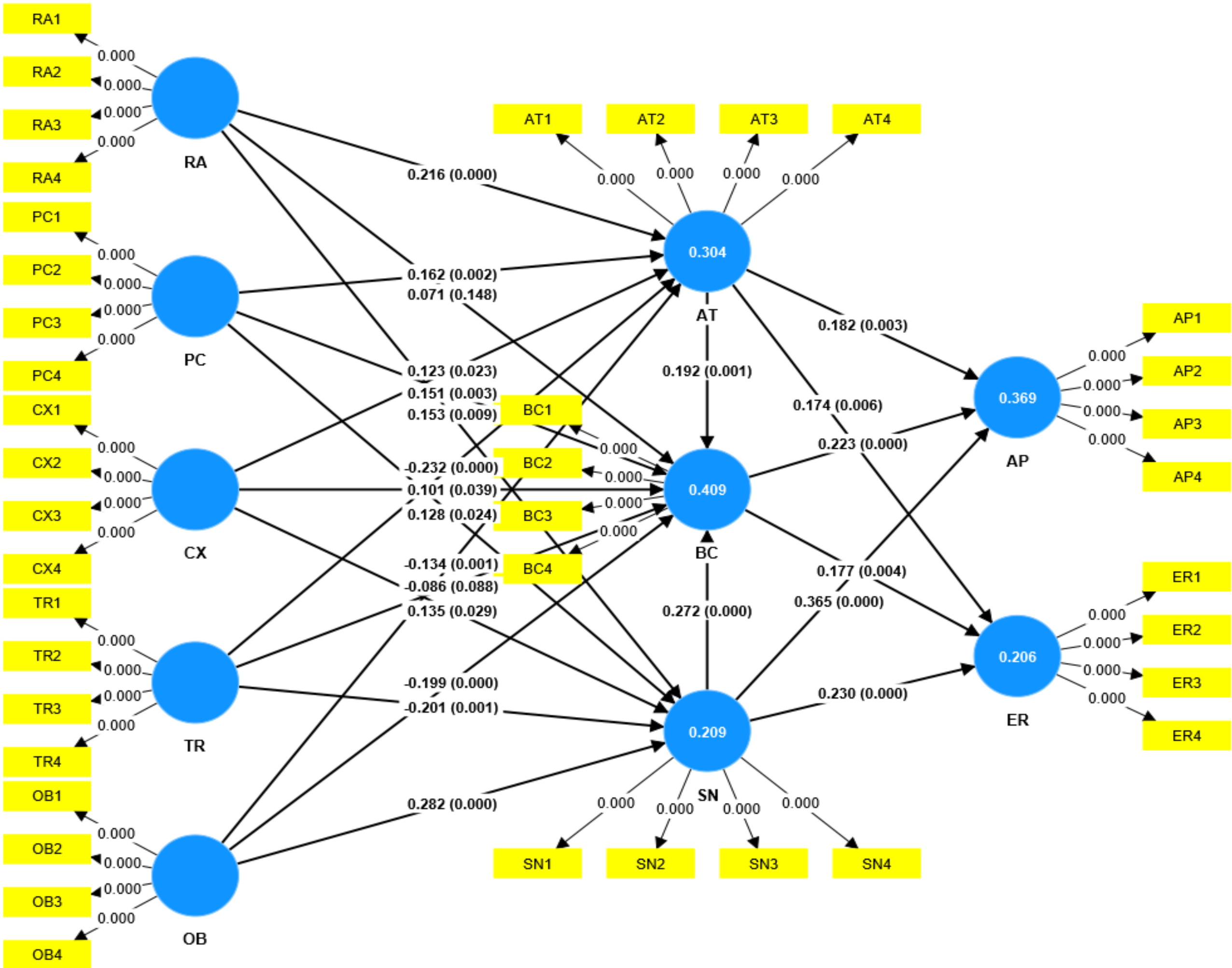

Figure 2.
Structural model results of circular economy practice adoption.
Note: Perceived relative advantage (RA), Perceived compatibility (PC), Perceived complexity (CX), Perceived trialability (TR), Perceived observability (OB), Attitude toward sustainable agricultural practices (AT), Subjective norms (SN),
Perceived behavioral control (BC), Adoption of sustainable farming practices (AP), Economic resilience of farmers (ER).

5. Discussion

This study sheds light on the key behavioral factors driving the adoption of circular economy (CE) practices in agriculture, highlighting farmers' stronger preference for sustainable farming practices (AP) over economic resilience (ER). The results reveal the complex interplay between the Diffusion of Innovations (DOI) attributes and the Theory of Planned Behavior (TPB) constructs, providing deep insights into farmers' decision-making processes.

First, the study identifies that relative advantage and perceived compatibility significantly enhance attitude, subjective norms, and perceived behavioral control. This finding aligns with previous research, showing that when farmers recognize the economic and environmental benefits of circular economy (CE) practices, they develop more favorable attitudes toward adoption [13]. Similarly, the perception that CE practices are compatible with traditional farming methods enhances farmers' willingness to adopt them [12]. Moreover, subjective norms (SN) emerge as a key driver of adoption practices, highlighting the influence of social pressure and community acceptance in shaping adoption behavior. This is consistent with findings that support from peers, policymakers, and consumers reinforces social pressure, thereby promoting the adoption of sustainable practices [14].

However, not all DOI attributes have positive effects. Perceived observability and trialability negatively impact AT and BC. When farmers struggle to observe tangible benefits or feel uncertain during experimentation, their confidence in adopting new practices declines. This aligns with published results on farmers' intentions to intercrop in Sweden, which found that trialing new practices can cause anxiety if the process is too complex or risky. Therefore, policymakers should focus on providing structured demonstration projects and trial programs to reduce uncertainty and build farmers' confidence [25].

Another notable finding is that perceived complexity (CX) does not influence SN, indicating that complexity does not necessarily create social pressure. Similarly, OB does not significantly affect SN, suggesting that observability may shape attitudes and behavioral control but not social norms. These findings resonate with Swart et al. [20], who highlighted that psychological and social factors may vary depending on specific contexts. Thus, further research is needed to explore context-specific barriers affecting adoption behavior in different farming communities.

Furthermore, this study approaches the theory of planned behavioral constructs that play a crucial mediating role, linking DOI attributes to behavioral outcomes. SN has the strongest effect on AP, emphasizing the importance of social networks, policy support, and community engagement in driving adoption. This aligns with [18] who found that social group support creates strong motivation for farmers to adopt sustainable practices. Additionally, AT and BC positively influence both AP and ER, confirming that farmers with strong control beliefs and positive perceptions of sustainability are more likely to adopt CE practices and achieve economic benefits. These results suggest that interventions should leverage social networks and enhance farmers' confidence through training, incentives, and peer influence mechanisms.

6. Conclusion

This study provides valuable insights into the adoption of circular economy (CE) practices in agriculture, considering both demographic factors and behavioral influences. The surveyed farmers represent a diverse demographic landscape, with variations in age, education, land ownership, and cooperative membership. These factors shape their access to resources, exposure to innovation, and willingness to adopt sustainable practices. The majority of respondents own their farmland, indicating a stable agricultural base, while cooperative membership remains relatively low, potentially affecting access to financial and technical support. These demographic characteristics provide important context for understanding how different farmer groups respond to innovation adoption.

The findings confirm that the diffusion of innovations (DOI) attributes play a significant role in influencing farmers' attitudes and behavioral intentions. Relative advantage (RA) and perceived compatibility (PC) positively impact attitude (AT), subjective norms (SN), and perceived behavioral control (BC), reinforcing that farmers are more likely to adopt CE practices when they perceive clear economic and environmental benefits and when these innovations align with their traditional farming methods. However, perceived observability (OB) and perceived trialability (TR) negatively affect AT and BC, indicating that uncertainty and difficulty in observing tangible benefits may discourage adoption. These findings highlight the need for effective communication, demonstration projects, and structured trial programs to reduce perceived risks.

Furthermore, the theory of planned behavior (TPB) explains how DOI constructs shape behavioral outcomes, with SN playing the strongest role in driving adoption. The study confirms that SN significantly influences AP, demonstrating that social pressure, peer influence, and policy support are critical motivators. Additionally, AT and BC positively affect both AP and economic resilience (ER), indicating that farmers who have positive perceptions and confidence in their ability to implement CE practices are more likely to engage in sustainable agriculture while experiencing economic benefits.

Given this dynamic, the surveyed farmers prioritize the adoption of sustainable farming practices (AP) over economic resilience (ER). This suggests that environmental concerns and social norms play a more significant role in shaping adoption behavior than direct financial gains. Policymakers and agricultural organizations should leverage social networks, cooperative support, and targeted training programs to enhance adoption rates, ensuring that CE practices are both accessible and practical for farmers.

7. Implications

The study highlights the influence of demographic factors such as gender, age, cooperative membership, and land ownership on the adoption of circular economy (CE) practices in agriculture. Policymakers should design targeted training programs and incentives, particularly for young and middle-aged farmers, who show higher adoption potential. Strengthening cooperative structures is also crucial, as 65.40% of farmers operate independently, limiting access to resources and knowledge sharing. Additionally, emphasizing the economic and environmental benefits (RA) of CE practices and ensuring their compatibility (PC) with traditional farming methods can enhance farmers' attitudes and perceived control, driving higher adoption rates [40].

Building on these practical insights, the study also underscores the critical role of social norms (SN) in driving CE adoption. Peer influence, community engagement, and policy support are key factors that shape farmers' decisions. To leverage this, initiatives such as farmer-led demonstrations and policy-driven incentives should be prioritized [41]. However, the negative impact of perceived observability (OB) and trialability (TR) on attitude (AT) and behavioral control (BC) highlights the need for clear evidence of CE benefits. Implementing demonstration farms, case studies, and structured trial programs can help farmers visualize tangible outcomes, reducing uncertainty and boosting confidence in adopting sustainable practices.

Despite these valuable findings, the study has certain limitations that open avenues for future research. For instance, some DOI attributes, such as perceived complexity (CX) and observability (OB), did not significantly influence subjective norms (SN), suggesting that social pressure alone may not suffice. Future research should explore additional factors shaping social norms, including trust in policies, cooperative engagement, and consumer-driven sustainability trends [42]. Regional variations in behavioral influences and economic conditions should also be examined to better understand adoption barriers. Moreover, longitudinal studies are needed to assess the long-term effects of SN, AT, and BC on sustained adoption and economic resilience [43]. Finally, investigating the interplay between sustainability norms and agricultural innovation could offer new strategies for accelerating CE adoption across diverse socio-economic and environmental contexts [44].

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