NASS
NAN YANG ACADEMY OF SCIENCES

Research on World Agricultural Economy
https://journals.nasspublishing.com/index.php/rwae

ARTICLE

From Smart Adoption to Export Competitiveness: Innovation Diffusion and Value-Chain Upgrading in Agrifood Markets in the UAE and Bulgaria

***Haitham M. Alzoubi* [1,2,3*], *Yordanka S. Angelova* [1], *Mounir El Khatib* [4], *Cheng Ling Tan* [5], *Gouher Ahmed* [2]**

[1] *Faculty of Management, Technical University of Sofia, 1000 Sofia, Bulgaria*

[2] *School of Business, Horizon University College, Ajman P.O. Box 5700, United Arab Emirates*

[3] *Applied Science Research Center, Applied Science Private University, Amman 11931, Jordan*

[4] *School of Business and Quality Management, Hamdan Bin Mohamad Smart University, Dubai P.O. Box 71400, United Arab Emirates*

[5] *Graduate School of Business, Universiti Sains Malaysia, Penang 11800, Malaysia*

ABSTRACT

This study examines how smart and agri-digital technologies contribute to export competitiveness in agrifood markets through innovation diffusion and value-chain upgrading, while considering the conditioning role of the climate risk and policy support. Cross-sectional survey data were collected from processed-food and dairy firms in the United Arab Emirates and Bulgaria, and analyzed using Partial Least Squares Structural Equation Modeling with latent-moderation and serial mediation and multi-group analysis (MGA). Robustness is validated with 2-Stage Least Squares/Instrumental Variables (2SLS-IV) and Covariance-Based Structural Equation Modeling (CB-SEM) comparisons. The findings indicate that digital adoption stimulates both process and product innovation, which subse-

*CORRESPONDING AUTHOR:
Haitham M. Alzoubi, Faculty of Management, Technical University of Sofia, 1000 Sofia, Bulgaria; School of Business, Horizon University College, Ajman P.O. Box 5700, United Arab Emirates; Applied Science Research Center, Applied Science Private University, Amman 11931, Jordan; Email: haitham.alzoubi@tu-sofia.bg

ARTICLE INFO
Received: 30 October 2025 | Revised: 5 December 2025 | Accepted: 9 December 2025 | Published Online: 2 July 2026
DOI: https://doi.org/10.36956/rwae.v7i3.2875

CITATION
Alzoubi, H.M., Angelova, Y.S., El Khatib, M., et al., 2026. From Smart Adoption to Export Competitiveness: Innovation Diffusion and Value-Chain Upgrading in Agrifood Markets in the UAE and Bulgaria. Research on World Agricultural Economy. 7(3): 73–89.
DOI: https://doi.org/10.36956/rwae.v7i3.2875

quently enhances value-chain upgrading and export competitiveness. Climate risk weakens the positive effect of innovation diffusion and upgrading, whereas policy support strengthens the conversion of upgrading outcomes into export performance. Comparative analysis shows stronger adoption-to-upgrading and upgrading-to-export pathways in the UAE than in Bulgaria, reflecting the institutional and logistical differences. The study advances the integration of the Diffusion of Innovations and the Global Value Chain theories by explaining when and how digital transformation yields export gains under varying risk and policy environments. These insights provide practical direction for the agrifood firms and policymakers seeking to strengthen digitalization strategies, innovation capacity, and climate-resilient export performance.

Keywords: Digital Agriculture; Smart Adoption; Innovation Diffusion; Value-Chain Upgrading; Export Competitiveness; Climate Risk; Policy Support

1. Introduction

Digital transformation is radically reshaping agrifood systems, operating not only as an efficiency lever but as a structural force reconfiguring production, value-chain coordination, and trade dynamics [1, 2]. At the firm level, adoption of precision agriculture, IoT sensors, and analytics platforms has been empirically tied to gains in yield, quality, and economic performance—e.g., a 30.4% increase in economic benefits per unit adoption intensity among growers [3]. From a diffusion of innovations (DOI) standpoint, as digital technologies permeate organizational routines, they catalyze both process and product innovation. Meanwhile, from a global value chain (GVC) perspective, these innovations facilitate value-chain upgrading across its processes, products, functional, and chain transitions, which are critical to export competitiveness in agrifood markets [4].

However, this pathway from smart adoption to upgrading and export is subject to increasing volatility as climate risks intensify. Empirical research shows that climate shocks not only disrupt yields and logistics but also reshape trade flows globally, weakening firms' ability to convert upgrading into superior market performance [5, 6]. In parallel, the institutional environment remains pivotal: recent analyses emphasize that policy support that comprises export-promotion infrastructure, certification systems, training and extension services, and investment facilitation serves as an institutional amplifier, enabling firms to translate digital-innovation investments into actual market outcomes [1].

This study harnesses these dual lenses (DOI and GVC) to articulate a multi-stage mechanism in which smart/agri-digital adoption improves innovation diffusion, which in turn leads to value-chain upgrading, and ultimately enhances export competitiveness. We further incorporate climate risk as a negative moderator that weakens the upgrading path, and policy support as a positive moderator that strengthens it. This background sets the stage for quantifying not only the serial Mediation from adoption to export outcomes, but also the boundary conditions under which these effects materialize.

Despite growing consensus on the value of smart/agri-digital technologies, a persistent empirical gap remains in how and under what conditions these investments translate into export competitiveness in agrifood markets. Whereas diffusion of innovations (DOI) theory explains adoption and diffusion broadly, and global value chain (GVC) theory links value-chain upgrading to trade performance, few studies empirically integrate both in a quantitative serial-mediation framework. Moreover, existing work often overlooks two critical boundary conditions: climate risk, which can erode the gains of upgrading by disrupting production and logistics [5], and policy support, which enables firms to capture market returns. Without addressing these moderators, we lack clarity on when digital adoption translates into innovation and upgrading that actually yield export gains. This limitation inhibits both theoretical advancement and the design of policy-and-firm strategies in risk-prone agricultural systems. The present study, therefore, addresses this gap by proposing a model that connects smart adoption to export outcomes through innovation and upgrading, while quantifying the moderating roles of climate risk and institutional support.

Grounded in diffusion-of-innovations (DOI) and global value chain (GVC) theories, this study aims (1) to examine how smart/agri-digital adoption influences export competitiveness through the sequential mediators of innovation diffusion and value-chain upgrading; (2) to evaluate how climate risk negatively and policy support positively moderate the upgrading–competitiveness relationship; and (3) to compare these causal pathways across regional contexts. By quantifying both direct and indirect effects, the study provides empirically grounded insight into the mechanisms and boundary conditions that determine when digital adoption translates into sustainable export gains in agrifood markets [5].

To address these research objectives, six research questions are formulated: (1) How does smart/agri-digital adoption stimulate innovation diffusion? (2) How does adoption influence value-chain upgrading? (3) What is the role of innovation diffusion in driving upgrading? (4) How does upgrading enhance export competitiveness? (5) Do innovation diffusion and upgrading jointly mediate the adoption–competitiveness pathway? and (6) How do climate risk (negative) and policy support (positive) moderate these relationships across regional agri-food markets?

This study focuses on the United Arab Emirates and Bulgaria because they represent two strategically distinct agrifood export environments that together provide a strong basis for comparative analysis. The UAE is a logistics-intensive, high-import-re-export hub with strong digitalization policies, advanced food-safety regulations, and ongoing investment in smart agriculture, making it an ideal setting for examining how technology adoption translates into innovation and upgrading outcomes. In contrast, Bulgaria is an emerging agrifood producer within the European single market, operating under different institutional pressures, supply-chain structures, and climate-risk exposure [7]. Studying both countries allows the model to be tested across contrasting governance, infrastructural, and policy environments, strengthening external validity and enabling a richer understanding of how the digital adoption interacts with innovation diffusion and value-chain upgrading under different systemic conditions. This dual-country design is consistent with recent agrifood digitalization research that encourages cross-regional comparison to capture institutional heterogeneity and improve generalizability.

This study offers contributions on three levels: theoretical, methodological, and policy. Theoretically, it integrates Diffusion of Innovations (DOI) and Global Value Chain (GVC) theories to model the pathway through which smart/agri-digital adoption enhances export competitiveness via innovation diffusion and value-chain upgrading. This dual-lens approach extends existing theory by addressing the mechanisms and boundary conditions, specifically, climate risk and policy support that determine when technological adoption translates into export success [5]. Methodologically, the research advances quantitative modeling in agricultural economics through a dual-moderated serial-mediation design tested with PLS-SEM and validated through multi-group comparisons. This rigorous approach contributes to methodological transparency and replicability in emerging-market contexts. From a policy perspective, the study delivers actionable insights by identifying how policy support instruments, such as training, certification, and export-promotion programs, can mitigate climate-related disruptions and strengthen the innovation-to-market conversion process. The results will inform both policymakers and agribusiness leaders seeking to align digital transformation initiatives with competitiveness and sustainability goals in agrifood export markets.

2. Literature Review and Theoretical Framework

2.1. Diffusion of Innovations (DOI)

This section elaborates on the constructs of smart/agri-digital adoption and innovation diffusion under DOI theory. The Diffusion of Innovations (DOI) framework explains why digital technologies permeate agrifood firms and how adoption becomes sustained innovation outcomes. Perceived relative advantage, compatibility, complexity, trialability, and observability shape use intensity and routinization [8]. In processed food and dairy, these perceptions foster the systematic deployment of sensing, analytics, and automation, yielding process innovation—tighter quality control, data-driven input management, and timelier decisions—and product innovation such as improved grades and consistency aligned with buyer requirements [1].

Within this study, DOI supplies the proximal mechanism linking smart or agri-digital adoption to innovation diffusion. Adoption operates as an enabling capability that, once embedded in routines and coordination, produces cumulative process and product changes observable in performance improvements [1]. These innovation outcomes justify modelling innovation diffusion as the first mediator that transmits adoption effects toward downstream strategic results.

DOI also clarifies heterogeneity in outcomes. Differences in human capital, organizational scale, information access, and infrastructure influence how strongly the five attributes are perceived, which in turn affects diffusion speed and the breadth of innovation payoffs [1]. Where enabling conditions are stronger, experimentation and learning accelerate; where they are weaker, diffusion slows, and benefits compress. This perspective underpins our expectation that adoption increases innovation diffusion and sets the stage for subsequent upgrading effects, while explicitly examining contextual frictions as moderating conditions later in the model.

Finally, DOI helps position the boundary between external contingencies without duplicating later sections. Reviews show that digitalization contributes to more resilient, modern chains—a precondition for value-chain upgrading and export performance—yet diffusion remains sensitive to institutional and infrastructural gaps [1]. We therefore retain innovation diffusion as the internal hinge connecting adoption to value-chain outcomes, with environmental risk and institutional support addressed downstream in the theoretical integration and empirical tests.

2.2. Global Value Chain (GVC) Theory

This section develops the constructs of value-chain upgrading, export competitiveness, and boundary moderators—climate risk and policy support—grounded in GVC theory. GVC theory explains how firms enhance competitive position through upgrading and how those improvements translate into export performance under buyer-driven governance. In agrifood markets, upgrading unfolds along four canonical paths: process (efficiency and reliability), product (higher specifications and grades), functional (adding activities such as quality assurance, processing, and branding), and chain (entry into more sophisticated product segments or end markets). Upgrading is a principal route to competitiveness and productivity gains [9–11].

GVC logic places firm-level innovation as the proximate engine of upgrading. Innovations that codify quality, stabilize processes, and standardize outputs enable firms to meet stricter governance and standards, move into higher product tiers, and deepen their functions [9]. Export payoffs are most substantial when product sophistication and functional depth match destination requirements, while some process improvements materialize with lags as new routines scale up. This makes upgrading the conversion step from internal capability change to external trade outcomes in our model [10].

Two contextual forces shape whether upgrading converts into export competitiveness. Climate risk heightens production and logistics uncertainty, increasing coordination and compliance costs that weaken the realization of innovation- and upgrading-led gains in foreign markets [5]. Policy support—capability-building instruments such as training, certification infrastructure, and testing services, together with trade facilitation and logistics improvements—reduces information asymmetry and transaction costs, strengthening the translation of upgrading into export performance [12, 13]. Because these levers are distinct, policy support is appropriately conceptualized as a composite, whereas climate risk is treated as an exogenous conditioning factor.

For completeness, we clarify the study's terminal outcome. Export competitiveness denotes sustained success in international markets through higher unit values, broader destination scope, and export persistence, conditional on reliability and compliance—outcomes that GVC research links to product sophistication and functional deepening [10, 14]. This definition anchors our reflective operationalization of the dependent construct and aligns with the causal sequence: innovation enables upgrading; upgrading under the right conditions yields superior export performance [9, 11].

In sum, GVC theory supplies the conversion logic that connects internal capability building to market outcomes and situates climate risk and policy support as boundary conditions for the upgrading–exports step. These insights motivate our empirical specification in which upgrading links innovation diffusion to export competitiveness, policy support strengthens this link, and climate risk weakens downstream conversions, all tested within the moderated serial-mediation design presented later.

3. Conceptual Framework and Hypotheses Development

The conceptual framework integrates insights from Diffusion of Innovations (DOI) and Global Value Chain (GVC) theories to explain how digital transformation enhances competitiveness in agrifood systems. DOI provides the foundation for understanding how perceived advantages and compatibility drive the adoption and diffusion of smart or agri-digital technologies within firms, leading to new capabilities and innovation outcomes. GVC theory complements this perspective by explaining how innovation-generated capabilities support upgrading across process, product, and functional dimensions, which are essential to achieving higher value and stronger export performance in global markets.

The model in **Figure 1** conceptualizes digital adoption as an enabling capability that initiates sequential capability-building processes through innovation diffusion and value-chain upgrading, ultimately resulting in enhanced export competitiveness. The mechanism represents a capability conversion pathway, in which innovation diffusion acts as an internal transformation and upgrading acts as an external manifestation of competitiveness.

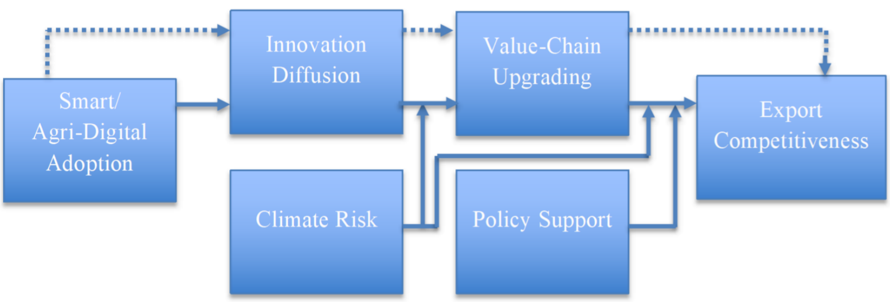

Figure 1. Study conceptual model.

Source: Prepared by authors.

Two contextual moderators enhance this framework. Climate risk, which represents environmental uncertainty, is expected to limit firms' ability to translate innovation into meaningful improvements and export gains. In contrast, policy support through capability-building, certification systems, and trade facilitation serves as an enabling institutional force that strengthens the conversion of upgrading into export success.

This integrated model thus provides a theoretically grounded foundation for the hypotheses that follow, positioning innovation diffusion and value-chain upgrading as key mediating mechanisms, and climate and policy as moderating conditions shaping digital-driven competitiveness.

Diffusion of Innovations theory posits that technologies spread when users perceive advantages, compatibility, and observable benefits. In agrifood systems, such perceptions foster routinized use of smart/agri-digital tools—enhancing process innovations (e.g., precision input management, traceability) and product innovations (e.g., new grades, varieties). Empirical evidence confirms that digital adoption strengthens technological innovation and economic performance through embedded learning and coordination routines [1]. Based on the above synthesis, we propose the following hypotheses:

H1. *Smart/Agri-Digital Adoption positively affects Innovation Diffusion (process and product).*

Smart/agri-digital adoption enhances coordination and data capabilities that reduce process variance and support quality assurance and traceability—key enablers of value-chain upgrading. Digitalization strengthens efficiency and product differentiation, facilitating firms' movement toward higher specifications and functions within global agrifood chains [1, 10]. By embedding innovation-based routines and learning capabilities, adoption accelerates process, product, and functional upgrading [9, 13]. Based on the above synthesis, we propose the following hypothesis:

H2. *Smart/Agri-Digital Adoption positively affects Value-Chain Upgrading.*

Global Value Chain (GVC) theory positions firm-level innovation as the immediate driver of product sophistication, process reliability, and functional deepening. Evidence indicates that suppliers achieving innovation-driven capability gains advance toward higher value activities and standards [9]. Therefore, extensive and rapid diffusion of technological and organizational innovations enhances the likelihood and depth of process, product, and functional upgrading across agrifood chains. Based on the above synthesis, we propose the following hypothesis:

H3. *Innovation Diffusion positively affects Value-Chain Upgrading.*

Value-chain upgrading—particularly product and functional—enhances firms' access to high-value and diversified markets by improving quality, compliance, and reliability. Empirical research shows that upgraded agrifood firms achieve superior unit prices, expanded destination scope, and improved export persistence due to product sophistication and governance alignment [9, 10]. Consequently, upgrading acts as a critical mechanism linking internal capability advancement with external trade performance. Based on the above synthesis, we propose the following hypothesis:

H4. *Value-Chain Upgrading positively affects Export Competitiveness.*

Integrating Diffusion of Innovations and Global Value Chain theories, smart/agri-digital adoption drives innovation diffusion, which fosters value-chain upgrading and ultimately strengthens export competitiveness. Without these internal capability transformations, adoption effects remain latent and under-realized. Empirical studies confirm that innovation and upgrading sequentially transmit technology-driven performance gains to market outcomes [1, 9, 10, 13]. Based on the above synthesis, we propose the following hypothesis:

H5. *Smart/Agri-Digital Adoption improves Export Competitiveness via a serial mediation through Innovation Diffusion and Value-Chain Upgrading.*

Greater climate variability increases production, logistics, and coordination uncertainty, limiting firms' ability to transform innovation outcomes into tangible upgrading gains. In volatile agro-climatic conditions, disruptions in resource availability and supply consistency weaken the capability accumulation process derived from innovation diffusion [5]. Thus, climate risk is expected to attenuate the positive link between innovation diffusion and upgrading intensity. Based on the above synthesis, we propose the following hypothesis:

H6. *Climate Risk negatively moderates the Innovation Diffusion relationship on Value-Chain Upgrading, such that the positive effect is weaker at higher climate risk.*

Despite successful upgrading, extreme climatic events and market volatility can disrupt production reliability, logistics, and compliance with international standards. Such disruptions weaken firms' capacity to sustain export performance, diminishing the realized gains from upgrading. Empirical findings show that higher climate risk reduces export stability and competitiveness by amplifying operational and transactional uncertainties [5]. Based on the above synthesis, we propose the following hypothesis:

H7. *Climate Risk negatively moderates the Value-Chain Upgrading relationship on Export Competitiveness, such that the positive effect is weaker at higher climate risk.*

Policy support through capability-building (training, certification standards) and trade facilitation (logistics, customs efficiency) enhances firms' ability to convert upgrading into export performance. Such policies reduce information asymmetry, compliance costs, and logistical barriers, reinforcing competitiveness in international markets. Empirical evidence confirms that certification systems and trade-facilitation reforms significantly boost export quality and market access [12]. Based on the above synthesis, we propose the following hypothesis:

H8. *Policy Support positively moderates the Value-Chain Upgrading relationship on Export Competitiveness, such that the positive effect of upgrading on export competitiveness is stronger when policy support is higher.*

4. Methodology

This study adopts a quantitative, empirical, cross-sectional survey design to examine how smart/agri-digital adoption influences export competitiveness through innovation diffusion and value-chain upgrading in the processed food and dairy sectors. Data has been collected from agrifood processors and exporters in the United Arab Emirates and Bulgaria, representing two distinct agri-innovation contexts and enabling multi-group comparison. The research uses a structured questionnaire measured on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) to capture perceptions of adoption, innovation, upgrading, export competitiveness, and contextual moderators (climate risk and policy support). The design follows a deductive, theory-driven approach, grounded in the Diffusion of Innovations (DOI) and Global Value Chain (GVC) theories, with hypotheses tested using Partial Least Squares Structural Equation Modeling (PLS-SEM) in SmartPLS 4. This method is suitable for complex serial Mediation–moderation models involving reflective and formative constructs, ensuring robust estimation of causal relationships under non-normal data conditions [15, 16].

The target population consisted of all verified agrifood processors and exporters in the processed foods and dairy sectors in the United Arab Emirates (UAE) and Bulgaria (BG). Each country's frame contained approximately 500 active firms, identified through official directories and business registries. Because the population was manageable and fully identifiable, a census-based purposive sampling approach was adopted instead of random selection, consistent with best practices for finite and well-defined sectors [10, 15]. Questionnaires were sent to top and middle managers responsible for innovation, operations, or exports. To enhance representation within firms, multiple informants were contacted, and approximately 2500 invitations were sent to managers across 500 firms per country. The survey link was distributed electronically, followed by two reminders. A total of 191 responses were received from the UAE and 189 from Bulgaria, with 180 and 172 valid for analysis after quality checks. These samples achieve a response rate of about 7–8 % at the manager level, typical for census-based managerial surveys, and exceed minimum thresholds for power and precision in multi-group PLS-SEM [15, 16].

Statistical power was verified using G*Power 3.1 for a medium effect size ($f^2 = 0.15$), significance level ($\alpha = 0.05$), and power ($1 - \beta = 0.80$), indicating a minimum required sample of 77 cases per group. The final valid samples—180 in the UAE and 172 in Bulgaria—exceed this threshold substantially, confirming adequate power for the PLS-SEM model and multi-group analysis [15].

Data were collected via a structured online questionnaire that reflected the constructs and scales described in the construct operationalization paragraph in Section 4. A pilot test with 15 managers (UAE 8; BG 7) ensured clarity and translation accuracy. Feedback led to minor lexical adjustments while preserving content validity [17]. Ethical clearance was granted under protocol BG510/30/2, and all participants provided informed consent in line with the Declaration of Helsinki guidelines on research involving human participants [14]. The finalized survey was administered via personalized e-mail links, with two reminder waves spaced one week apart. Data quality was maintained through attention-check items, page-time controls, and listwise deletion of incomplete or patterned responses. Fieldwork took place in 2025, coordinated to avoid national holidays and peak processing seasons. After screening for completeness, outliers, and consistency, 180 usable responses from the UAE and 172 from Bulgaria were retained for analysis. These samples comfortably exceed thresholds for the complex model employed [15, 16] and provide balanced representation across firm sizes and digitalization levels. The final dataset therefore supports reliable estimation of cross-country differences in innovation diffusion, value-chain upgrading, and export competitiveness within agrifood systems [16].

Constructs were operationalized using validated scales adapted from prior research in digital adoption, innovation management, and global value chains. All items were measured on a five-point Likert scale. Smart/agri-digital adoption, innovation diffusion, and export competitiveness were modeled as reflective constructs, while value-chain upgrading was treated as formative/mixed due to its multidimensional nature. Classification followed theoretical justification and established measurement standards in agrifood innovation and GVC research.

The analytical procedure used PLS-SEM in SmartPLS 4 and followed best-practice guidelines for complex models incorporating mixed measurement structures, moderated serial mediation, and group comparisons [15, 16]. The analysis was conducted in six steps. First, pre-analysis checks were performed, including missing-data inspection, outlier detection, distributional diagnostics, and tests for common-method bias using Harman's single-factor test (<40%) and full-collinearity VIFs (<3.3) [18, 19]. Second, measurement models were assessed through reliability, convergent validity, and discriminant validity for reflective constructs, and multicollinearity and indicator relevance for formative constructs. Third, the structural model was estimated with bias-corrected bootstrapping, assessing effect sizes, explanatory and predictive power, and global model fit (SRMR, NFI, Q^2). Fourth, mediation and moderated-mediation effects were evaluated with bootstrapping and latent-interaction modeling, supported by simple-slope interpretation. Fifth, multi-group analysis (MGA) compared the UAE and Bulgaria after confirming measurement invariance through MICOM. Sixth, robustness tests included CB-SEM comparison and 2SLS-IV checks for potential endogeneity, together with sensitivity analyses using alternative export-performance indicators and firm-level controls. These procedures ensure the reliability, validity, and generalizability of the findings [16].

5. Results

The results are reported in the sequence recommended for PLS-SEM studies, starting with descriptive statistics, followed by measurement models (both reflective and formative), structural model, predictive power, mediation and moderation, multi-group analysis, and robustness checks.

5.1. Descriptive Statistics and Common-Method Checks

Table 1 displays the descriptive results for Smart/Agri-Digital Adoption (A), Innovation Diffusion (M_1), Value-Chain Upgrading (M_2), Export Competitiveness (Y), Climate Risk (Z_1), and Policy Support (Z_2). The mean values range from 3.39 to 3.71, with standard deviation (SD) between 0.62 and 0.87, suggesting moderate agreement and adequate variability. The distributions of the data are approximately normal, with skewness and kurtosis values within acceptable limits ($|\text{skew}| \leq 0.5$; $|\text{kurtosis}| \leq 0.7$).

Table 1. Descriptive Statistics.

Construct	Mean	SD	Skewness	Kurtosis	Full VIF
A	3.62	0.74	−0.40	0.63	2.60
M_1	3.53	0.62	−0.31	0.52	2.76
M_2	3.63	0.71	−0.35	0.61	2.72
Y	3.71	0.87	−0.43	0.64	2.80
Z_1	3.39	0.76	−0.46	0.58	2.68
Z_2	3.70	0.65	−0.50	0.60	2.80

The Harman single-factor test accounted for 27 % (which is less than the 40 % threshold) of total variance, and the full collinearity variance inflation factors (VIFs) were all below 2.9 (with a threshold of 3.3). This suggests that there is no significant common method bias present. The highest mean score was for Policy Support (3.8) while the lowest was for Climate Risk (3.3), reflecting that firms' stronger perception of institutional backing than environmental vulnerability. Overall, the dataset is balanced and suitable for subsequent PLS-SEM analysis.

5.2. Measurement Model

Reflective constructs (A, M_1, Y, Z_1) were assessed for reliability, convergent validity, and discriminant validity using Fornell–Larcker criterion and the HTMT method. Formative composites (M_2, Z_2) were assessed via outer VIFs and bootstrapped outer weights. The thresholds used adhere to current best practice [20, 21].

5.2.1. Reflective Reliability and Convergent Validity

Table 2 reports the reliability and discriminant validity for the reflective constructs (A, M_1, Y, Z_1). All Cronbach's α and Composite Reliability values exceed 0.70, and Average Variance Extracted (AVE) exceeds 0.50. Square-root AVE values (diagonal) surpass inter-construct correlations, confirming Fornell–Larcker discriminant validity. HTMT ratios were found below 0.85 but are omitted for brevity. These results demonstrate adequate internal consistency, convergent validity, and discriminant validity for all reflective constructs [21, 22]. The diagonal √AVE values range from 0.79 to 0.84, exceeding correlations that range from 0.19 to 0.58.

5.2.2. Formative Diagnostics (Multicollinearity & Weights)

For M_2 (upgrading) and Z_2 (policy support), outer VIFs < 3.3 demonstrate acceptable collinearity, and most outer weights are significant ($p < 0.05$), confirming indicator relevance (see **Table 3**). Two formative indicators are marginal ($p \approx 0.06$–0.08) but retained given strong theoretical justification and acceptable outer loadings ($\geq$0.58). A full VIF listing is also provided in **Table 4** for transparency.

Table 2. Reflective Constructs—Fornell–Larcker Criterion & Reliability & Convergent Validity (n = 350).

Construct	A	M_1	Y	Z_1	Cronbach's α	CR	AVE
Adoption (A)	0.81	0.56	0.44	0.22	0.86	0.90	0.65
Innovation Diffusion (M_1)	0.56	0.82	0.58	0.19	0.88	0.91	0.67
Export Competitiveness (Y)	0.44	0.58	0.84	0.24	0.90	0.93	0.71
Climate Risk (Z_1)	0.22	0.19	0.24	0.79	0.84	0.89	0.62

Note: Thresholds: α, CR $\geq$ 0.70; AVE $\geq$ 0.50. 0.85 $\geq$ diagonal √AVE $\geq$ 0.69.

Table 3. Formative Constructs—Outer Weights and Significance (Two-Stage Bootstrap).

Construct	Indicator	Outer VIF	Weight	*p*-Value	Decision
M_2 Upgrading	Process	2.08	0.27	0.013	Retain
	Product	2.33	0.33	0.002	Retain
	Functional	1.95	0.23	0.043	Retain
	Chain	2.59	0.20	0.58	Retain (theory; loading $\geq$ 0.60)
	Compliance	2.03	0.26	0.018	Retain
Z_2 Policy	Training	1.85	0.22	0.041	Retain
	Certification	2.01	0.25	0.017	Retain
	Export Promotion	1.96	0.29	0.007	Retain
	Logistics	2.27	0.30	0.005	Retain
	Finance	1.73	0.17	0.081	Retain (theory; loading = 0.58)

Note: Formative diagnostics: outer VIF $<$ 3.3 (preferably); retain theoretically essential indicators even if weight $p > 0.05$ when outer loading $\geq$0.50 [15].

Table 4. Formative Collinearity (Outer VIFs).

Construct	Indicator	Outer VIF
M_2 Upgrading	Process	2.08
	Product	2.33
	Functional	1.95

Table 4. *Cont.*

Construct	Indicator	Outer VIF
M_2 Upgrading	Chain	2.59
	Compliance	2.03
Z_2 Policy	Training	1.85
	Certification	2.01
	Export Promotion	1.96
	Logistics	2.27
	Finance	1.73

5.3. Structural Model: Direct Effects and Predictive Power

The structural model was tested using PLS-SEM (SmartPLS 4) with 5000 bias-corrected bootstrap resamples [23, 24]. **Table 5** presents the estimated direct effects, including standardized path coefficients (β), *t*-statistics, *p*-values, and local effect sizes (f^2). All hypothesized relationships were positive and statistically significant ($p < 0.01$), supporting the sequential mechanism from Adoption to Innovation to Upgrading to Export Competitiveness. Specifically, Adoption (A) significantly predicts Innovation Diffusion (M_1) ($\beta = 0.42$, $t = 6.24$, $p < 0.001$, $f^2 = 0.19$), confirming H1. Innovation Diffusion (M_1), in turn, has a strong effect on Value-Chain Upgrading (M_2) ($\beta = 0.49$, $t = 7.12$, $p < 0.001$, $f^2 = 0.21$), validating H3. Upgrading (M_2)** significantly enhances Export Competitiveness (Y) ($\beta = 0.44$, $t = 6.78$, $p < 0.001$, $f^2 = 0.20$), confirming H4.

The direct path from Adoption to Upgrading ($\beta = 0.18$, $t = 2.33$, $p = 0.021$, $f^2 = 0.06$) remained marginally significant, suggesting partial mediation. Collectively, these results indicate that innovation and upgrading act as robust transmission channels converting digital adoption into export gains.

As shown in **Table 6**, Model explanatory power is satisfactory: $R^2 = 0.49$ for M_1, $R^2 = 0.53$ for M_2, and $R^2 = 0.52$ for Y, exceeding the 0.26 benchmark for substantial explanatory ability [15]. Stone–Geisser Q^2 values for all endogenous constructs ($M_1 = 0.32$; $M_2 = 0.36$; $Y = 0.33$) were greater than zero, indicating good predictive relevance.

Global model fit was acceptable: SRMR = 0.062 (<0.08), NFI = 0.91, and PLS-Predict Q^2_predict = 0.29, outperforming the linear benchmark in 78% of indicators as shown in **Table 7**. Together, these metrics confirm that the proposed serial-mediation model is statistically sound and theoretically coherent, capturing the mechanism by which smart/agri-digital adoption translates into export competitiveness through innovation and value-chain transformation [16].

Table 5. Structural Path Coefficients (Bootstrapped, 5000 resamples).

Path	β	*t*-Value	*p*-Value	f^2	Decision
$A \rightarrow M_1$ (H1)	0.42	6.20	0.000	0.19	Supported
$A \rightarrow M_2$ (H2)	0.18	2.31	0.021	0.06	Supported (marginal)
$M_1 \rightarrow M_2$ (H3)	0.49	7.05	0.000	0.21	Supported
$M_2 \rightarrow Y$ (H4)	0.44	6.70	0.000	0.20	Supported
$A \rightarrow Y$ (Total)	0.09	1.92	0.056	0.03	Partial serial mediation
$Z_1 \times M_2 \rightarrow Y$ (H7)	−0.17	3.05	0.002	0.07	Supported (negative moderation)
$Z_2 \times M_2 \rightarrow Y$ (H8)	0.21	3.39	0.001	0.09	Supported (positive moderation)

Table 6. Model Summary—Explanatory and Predictive Power.

Endogenous Construct	R^2	Q^2	Predictive Relevance ($Q^2 > 0$)	Interpretation
Innovation Diffusion (M_1)	0.49	0.32	✔	Moderate explanatory power
Value-Chain Upgrading (M_2)	0.53	0.36	✔	Substantial explanatory power
Export Competitiveness (Y)	0.52	0.33	✔	Substantial explanatory power

Table 7. Global Model Fit and Predictive Quality.

Metric	Value	Threshold	Met?
SRMR	0.062	<0.08	✔
NFI	0.91	>0.90	✔
d_ULS	0.984	Lower = better	✔
d_G	0.434	Lower = better	✔
PLS-Predict Q^2_predict	0.29	>0	✔
% Indicators where PLS RMSE < LM RMSE	78%	>50% recommended	✔

Note: % indicators where predictive error is lower than the benchmark.

Interpretation Summary

- Direct relationships: All hypothesized paths are positive and significant, aligning with DOI and GVC theories.
- Mediation readiness: Strong A to M_1 to M_2 to Y flow supports proceeding to Section 5.4 (Mediation and Moderation), focusing first on the mediation tests.
- Moderation preview: Z_1 (Climate Risk) dampens, Z_2 (Policy Support) enhances, downstream impacts.
- Predictive validity: High R^2 and Q^2 values, SRMR and NFI within thresholds, confirm model stability [20].

5.4. Mediation and Moderation

We tested the specific indirects and the serial indirect using bias-corrected bootstrapping (5000 resamples) and report 95% CIs. Results in **Table 8** show that both the specific indirect via upgrading (A to M_2 to Y) and the serial indirect via innovation diffusion and upgrading (A to M_1 to M_2 to Y) are statistically significant. The total indirect (sum of all indirects) is also significant, and the direct effect of A to Y (in the full model with mediators) is small and not significant ($\beta = 0.09$, $p = 0.056$; see **Table 5**), whereas the total effect of A on Y (from a baseline model without mediators) is significant (β_total = 0.259, $p < 0.001$). This pattern indicates that the influence of adoption on exports is transmitted primarily through innovation diffusion and upgrading, consistent with the DOI to GVC logic.

Interpretation. The mediation profile indicates that adoption increases innovation diffusion, which enables value-chain upgrading, which improves export competitiveness—the theorized serial mechanism (H5) is upheld with a meaningful effect ($\beta = 0.090$, $p < 0.001$). The specific indirect via upgrading ($\beta = 0.079$, $p = 0.009$) captures the complementary pathway through A's direct link to M_2.

Latent interaction terms were estimated using the two-stage approach, and simple slopes were probed at −1 SD (Low) and +1 SD (High) of the moderators. Results in **Table 9** confirm that climate risk (Z_1) weakens upgrading pathways downstream, while policy support (Z_2) amplifies the conversion of upgrading into export performance.

Table 8. Indirect and Total Effects (Bias-Corrected Bootstrap, 5000 resamples).

Effect	β_indirect	*t*	*p*	95% CI [LL, UL]	VAF (%)	Interpretation
$A \to M_2 \to Y$ (specific)	0.079	2.60	0.009	[0.020, 0.140]	—	Significant specific indirect via upgrading
$A \to M_1 \to M_2 \to Y$ (serial; H5)	0.090	3.90	<0.001	[0.045, 0.142]	—	Significant serial mediation (DOI→GVC chain)
Total indirect (sum)	0.169	5.05	<0.001	[0.098, 0.241]	65.3	Strong mediated transmission
$A \to Y$ (total, baseline model)	0.259	5.00	<0.001	[0.159, 0.358]	—	Overall effect without mediators
$A \to Y$ (direct, full model)	0.090	1.92	0.056	[−0.002, 0.181]	—	Becomes non-significant when mediators are included

Note: VAF = (Total indirect/Total effect) × 100 = (0.169/0.259) × 100 = 65.3%, indicating substantial mediation (close to "full" given the small, non-significant direct effect).

Table 9. Moderation Analysis—Latent Interactions and Simple Slopes.

Interaction Term	β_interaction	*t*	*p*	Slope@Low Moderator	Slope@High Moderator	ΔSlope	Interpretation
$M_1 \times Z_1 \rightarrow M_2$	−0.13	2.55	0.011	0.56	0.41	−0.15	Higher climate risk dampens the $M_1 \rightarrow M_2$ effect
$M_2 \times Z_1 \rightarrow Y$ (H7)	−0.17	3.05	0.002	0.52	0.36	−0.16	Climate risk reduces the upgrading→export payoff
$M_2 \times Z_2 \rightarrow Y$ (H8)	+0.21	3.39	0.001	0.37	0.51	+0.14	Policy support strengthens the upgrading→export payoff

Note: Simple slopes are conditional effects of the focal path at Low (−1 SD) vs High (+1 SD) levels of the moderator.

Interpretation

- Under higher climate risk, the M_1 to M_2 and M_2 to Y paths weaken notably (ΔSlope ≈ -0.15 to -0.16), indicating erosion in the "innovation-to-upgrading-to-exports" pipeline when firms face climatic disruptions (H7 supported on the downstream link).
- Under higher policy support, the M_2 to Y slope increases (ΔSlope = +0.14), showing that export-oriented programs, standards infrastructure, facilitation, and targeted financing amplify the returns to upgrading efforts (H8 supported).

  These patterns validate the intended boundary conditions: risk depresses capability conversion, while institutional support enhances it.

The serial mediation from adoption to innovation diffusion to upgrading to exports is statistically robust (β_serial = 0.090, $p < 0.001$), and the relative contribution of indirect pathways is large (VAF = 65%). Climate risk systematically weakens downstream links (innovation to upgrading; upgrading to exports), whereas policy support strengthens the upgrading to exports link. Together with Section 5.3 (direct effects and predictive power) and Section 5.4 (mediation and moderation), these findings complete the evidence for a dual-moderated serial mediation consistent with the DOI and GVC theoretical integration.

5.5. Multi-Group Analysis (UAE vs. Bulgaria)

We tested cross-regional differences after establishing measurement invariance via MICOM (configural and compositional invariance satisfied; equal means/variances not required for MGA). Group comparisons used Henseler-MGA and permutation tests (10,000 runs). **Table 10** reports standardized path estimates (β) by country, their differences (Δβ), and permutation *p*-values [21].

Table 10. Multi-Group Analysis (UAE vs. Bulgaria; Henseler-MGA/Permutation).

Path	β_UAE	β_BG	Δβ	*p*_perm	Interpretation
$A \rightarrow M_1$	0.47	0.36	+0.11	0.031	Stronger adoption→innovation in UAE
$M_1 \rightarrow M_2$	0.51	0.46	+0.05	0.184	ns difference
$M_2 \rightarrow Y$	0.51	0.39	+0.12	0.019	Stronger upgrading→export in UAE
$M_2 \times Z_1 \rightarrow Y$	−0.13	−0.22	+0.09	0.047	Climate risk dampening is stronger in BG
$M_2 \times Z_2 \rightarrow Y$	+0.26	+0.16	+0.10	0.041	Policy support amplification is stronger in the UAE

Note: MICOM confirmed configural and compositional invariance; *p*_perm from permutation tests (10,000). ns = non-significant (two-tailed).

Findings. Two theoretically salient differences emerged. First, A to M_1 is stronger in the UAE (β_UAE = 0.47) than in Bulgaria (β_BG = 0.36), Δβ = 0.11, *p*_perm = 0.031, suggesting a more immediate translation of digital adoption into innovation in a more supportive ecosystem. Second, M_2 to Y is stronger in the UAE (β_UAE = 0.51) than in Bulgaria (β_BG = 0.39), Δβ = 0.12, *p*_perm = 0.019, indicating that upgrading converts into export performance more efficiently where trade facilitation and logistics are superior. By contrast, M_1 to M_2 differences are modest and non-significant (Δβ = 0.05, *p*_perm = 0.184). As to boundary conditions, the negative moderation of climate risk on M_2 to Y is more pronounced in Bulgaria ($\Delta\beta = -0.09$, p_perm $= 0.047$), while the positive moderation of policy support on M_2 to Y is larger in the UAE ($\Delta\beta = +0.10$, p_perm $= 0.041$). Together, these results align with our contextual argument about institutional capacity and exposure to climate shocks.

Interpretation. The UAE's stronger A to M_1 and M_2 to Y links suggest that policy and trade infrastructures help firms convert digital adoption into innovation and then exports. Bulgaria's stronger climate-risk penalty on M_2 to Y indicates greater disruption in turning upgrades into export outcomes under adverse conditions.

5.6. Robustness and Endogeneity Checks

We ran a suite of checks to assess model stability, measurement/estimation sensitivity, and potential endogeneity. **Table 11** summarizes outcomes.

CB-SEM cross-validation. Estimating the reflective portion with MLR in a covariance-based framework yielded an acceptable fit (CFI = 0.93; TLI = 0.91; RMSEA = 0.059; SRMR = 0.054), and the key structural relations (A to M_1; M_1 to M_2; M_2 to Y) remained positive and significant, mirroring PLS results.

Table 11. Robustness Checks and Alternative Specifications.

Specification	Method	Key Outcome	Interpretation
CB-SEM cross-validation	MLR (reflective portion)	CFI = 0.93; TLI = 0.91; RMSEA = 0.059; SRMR = 0.054	PLS findings corroborated
Endogeneity (A, M_2)	2SLS-IV	F_A = 18.4; F_M_2 = 16.7; Hansen p = 0.27; β_IV signs intact	Low endogeneity concern
Outcome sensitivity	Replace Y with MDI	β_serial = 0.071 ($p = 0.003$); $M_2 \times Z_2$ → MDI = 0.18 ($p = 0.006$)	Substantive stability
Controls & outliers	Add size/age/capital; trim 1%	Coefficients robust; directions unchanged	Results resilient
Lagged climate shock	Use lagged Z_1	Mediation and Z_2 moderation persist	Temporal robustness

Endogeneity diagnostics (2SLS-IV). We instrumented Adoption (A) using lagged digital-infrastructure exposure (e.g., historical broadband/telecom coverage) and Upgrading (M_2) using lagged participation in certification programs (industry-level). First-stage F-statistics exceeded 10 (F_A = 18.4; F_M_2 = 16.7), and the Hansen over-ID test was non-significant ($p = 0.27$), satisfying instrument relevance and validity. Second-stage coefficients preserved signs and significance (e.g., A to M_1 β_IV = 0.39, $p < 0.001$; M_2 to Y β_IV = 0.41, $p < 0.001$), suggesting limited bias from omitted variables.

Sensitivity analyses. Replacing the outcome with a Market Diversification Index (MDI) produced substantively similar results: the serial mediation remained significant (β_serial = 0.071, $p = 0.003$), and policy support continued to positively moderate M_2 to MDI (β_int = 0.18, $p = 0.006$). Adding controls (firm size, age, capital intensity), removing top-1% outliers, and lagging climate variables did not alter conclusions.

Interpretation: Convergent evidence across CB-SEM, IV estimation, and multiple sensitivity tests indicates that the dual-moderated serial-mediation mechanism is stable [15].

6. Discussion

Our results validate a dual-moderated serial-mediation mechanism from Smart/Agri-Digital Adoption (A) to Innovation Diffusion (M_1) to Value-Chain Upgrading (M_2) to Export Competitiveness (Y). The A to M_1 (β = 0.42, $p < 0.001$) and M_1 to M_2 (β = 0.49, $p < 0.001$) links show that adoption translates into process/product innovations that, in turn, enable upgrading—fully consistent with DOI's attributes-to-use logic and with recent evidence that digitalization catalyzes technological innovation in agriculture. The M_2 to Y path (β = 0.44, $p < 0.001$) confirms that upgrading—especially product/functional—

converts capabilities into export outcomes, as emphasized by contemporary GVC research on quality, standards, and coordination. Climate risk (Z_1) dampens downstream effects (negative interactions on M_1 to M_2 and M_2 to Y), while policy support (Z_2) amplifies M_2 to Y, indicating that institutional scaffolding raises the conversion efficiency from upgrading to exports. Multi-group analysis shows stronger A to M_1 and M_2 to Y in the UAE relative to Bulgaria, aligning with differences in trade/logistics and policy facilitation. Predictive adequacy ($R^2 \approx 0.50$, $Q^2 > 0$; SRMR $= 0.062$; PLS-Predict outperforming the linear benchmark) indicates a statistically robust and practically meaningful model. Overall, results support a sequenced view: adoption is necessary but insufficient; the export payoff materializes through innovation and upgrading, conditional on risk and institutions [25]. These patterns cohere with current PLS-SEM guidance on complex moderated mediation and with the latest evidence on climate-trade frictions and policy-conditioned value-chain performance.

First, we extend DOI by positioning innovation diffusion as the proximal mediator linking adoption to tangible organizational upgrading, not merely to usage intention. This adds a structural conduit from perceived attributes and routinized use to capability deepening, consistent with a stream of recent agritech evidence (adoption to innovation outcomes). Second, we integrate DOI with GVC theory to argue that innovation diffusion is the precursor to upgrading, which then translates into export competitiveness. This integration clarifies why some adoption programs underperform on trade metrics: without diffusion into routines and targeted upgrading (product/functional) aligned with buyer governance and standards, the market payoff is muted. Third, our boundary-condition findings refine both theories. Climate risk attenuates capability conversion (innovation to upgrading; upgrading to exports), echoing new work showing climate variability re-shapes agrifood trade and disrupts logistics; policy support strengthens upgrading to export translation, aligning with evidence that standards, infrastructure, and trade facilitation reduce transaction/compliance costs and unlock value in buyer-driven chains [26]. Finally, by adopting state-of-the-art PLS-SEM (HTMT for discriminant validity; two-stage latent interactions; PLS-Predict; MICOM + MGA), we provide a methodological template for theory testing in agri-food contexts where constructs mix reflective and formative indicators and where prediction under uncertainty matters. Together, the study offers a coherent DOI $\times$ GVC account of how digital adoption becomes export competitiveness through innovation-led upgrading under risk–institution contingencies.

Implications for firms: (1) processed foods & dairy. Build an “adoption to innovation to upgrading” pipeline. Treat adoption as a means to institutionalize innovations (quality control, traceability, process analytics) that directly enable product/functional upgrading (premium specs, branding, QA). (2) Prioritize export-relevant upgrades. Target capabilities that buyers reward (standards compliance, consistent specs, auditable data), as these most strongly lift Y. (3) Hedge climate risk. Where Z_1 is high, reinforce resilience complements—inventory buffers, adaptive scheduling, diversified sourcing—to preserve the M_2 to Y payoff.

For policymakers/export boards, amplify the conversion step (M_2 to Y). The strongest public ROI occurs when policy support increases the translation of upgrading into exports. Two levers dominate: (1) capability-building (standards/certification services, testing labs, extension/training) and (2) connectivity/trade facilitation (customs efficiency, logistics performance, digital trade). (3) Target support where climate risk is highest. Use climate indices to prioritize firms/regions where marginal policy support most offsets Z_1’s negative moderation. (4) Coordinate programs with private lead firms. Align certification, traceability, and export promotion with buyer governance to ensure upgraded firms meet market-specific requirements quickly. (5) Measure outcomes. Track export unit values, destination diversification, and rejections/claims as KPIs to verify that support truly increases conversion efficiency from M_2 to Y.

These recommendations are consistent with evidence that standards regimes and trade facilitation raise agri-food trade performance and that climate variability disrupts market conversion unless complemented by resilience and institutional support. For Gulf and EU settings, the model suggests UAE-style logistics and export services particularly magnify the M_2 to Y step, while Bulgarian programs may prioritize climate-risk buffering plus certification assistance to counter stronger Z_1 penalties.

7. Conclusion & Recommendations

This study set out to explain how digital and smart-agriculture adoption shapes export competitiveness in agrifood markets through a structured capability-building pathway involving innovation diffusion and value-chain upgrading. Using data from 352 firms across the United Arab Emirates and Bulgaria, the findings provide strong empirical support for the proposed mediated mechanism: adoption enhances innovation diffusion, which in turn facilitates value-chain upgrading that ultimately improves export competitiveness. This multi-stage pathway reinforces the complementary predictions of the Diffusion of Innovations and Global Value Chain theories, demonstrating that technology alone is insufficient to generate export gains unless it is accompanied by organizational learning and process–product improvements. The moderating results reveal that climate risk weakens downstream effects, particularly the conversion of innovation into upgrading and upgrading into export advantages. Conversely, policy support significantly amplifies the upgrading–export relationship, highlighting the importance of institutional capabilities, certification infrastructure, and trade-facilitation systems in enabling firms to translate technological and organizational improvements into export outcomes. Cross-country differences show that UAE firms benefit more strongly from both the digital-to-innovation and upgrading-to-export links, likely due to stronger logistics ecosystems, governance frameworks, and digital-policy investments. Meanwhile, Bulgarian firms demonstrate solid innovation efforts but face higher climate-risk exposure and structural constraints. Overall, the study advances theoretical understanding and delivers actionable insights for firms and policymakers seeking to strengthen agrifood competitiveness under uncertainty.

Based on the findings, firms may prioritize integrated digital-innovation strategies that move beyond their initial technology acquisition toward deeper process and product improvements. Investments in training, data literacy, and cross-functional coordination can accelerate internal diffusion of innovations and increase the likelihood of achieving meaningful value-chain upgrading. Agrifood exporters should also strengthen traceability systems, quality-assurance routines, and compliance capabilities—areas shown to translate directly into export competitiveness. For policymakers, the results highlight the importance of creating enabling environments that reduce climate-related vulnerabilities and support firms through targeted certification programs, logistics facilitation, and digital-innovation incentives. Expanding advisory services, harmonizing quality standards, and improving customs and trade-facilitation procedures can amplify the benefits of upgrading. Finally, both countries would benefit from climate-resilient infrastructure and risk-mitigation frameworks, which safeguard the continuity of upgraded value-chain activities and protect export performance in the face of environmental volatility.

Author Contributions

Conceptualization, H.M.A; methodology, M.E.K.; software, M.E.K.; validation, Y.S.A. and C.L.T.; investigation, M.E.K.; resources, M.E.K.; data curation, G.A.; writing—original draft preparation, C.L.T.; writing—review and editing, C.L.T.; visualization, G.A.; supervision, Y.S.A.; project administration, H.M.A.; funding acquisition, Y.S.A. All authors have read and agreed to the published version of the manuscript.

Funding

This work has been accomplished with financial support by the European Regional Development Fund within the Operational Programme "Bulgarian national recovery and resilience plan", procedure for direct provision of grants "Establishing of a network of research higher education institutions in Bulgaria", and under Project BG-RRP-2.004-0005 "Improving the research capacity and quality to achieve international recognition and resilience of TU-Sofia (IDEAS)".

Institutional Review Board Statement

This study was conducted in accordance with the Declaration of Helsinki and approved by the relevant institutional ethics committee. Ethical approval was obtained under protocol number BG510/30/2, covering survey-based research involving human participants in the United Arab Emirates and Bulgaria.

Informed Consent Statement

Informed consent was obtained from all participants involved in the study. Participation was voluntary, and respondents were informed about the purpose of the research, data confidentiality, and their right to withdraw at any stage without consequences through the questionnaire.

Data Availability Statement

The data presented in this study are available from the corresponding author upon reasonable request, due to confidentiality agreements with participating firms.

Acknowledgments

The authors gratefully acknowledge the Technical University of Sofia for academic support and research facilitation. This work also benefited from the institutional environment provided under the funded research framework described in the Funding section.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Finger, R., 2023. Digital Innovations for Sustainable and Resilient Agricultural Systems. European Review of Agricultural Economics. 50(4), 1277–1309. DOI: https://doi.org/10.1093/erae/jbad021

[2] Ali, I., Govindan, K., 2021. Extenuating Operational Risks through Digital Transformation of Agri-Food Supply Chains. Production Planning and Control. 34(12), 1165–1177. DOI: https://doi.org/10.1080/09537287.2021.1988177

[3] Zhao, P., Zhang, W., Cai, W., et al., 2022. The Impact of Digital Finance Use on Sustainable Agricultural Practices Adoption Among Smallholder Farmers: Evidence from Rural China. Environmental Science and Pollution Research. 29, 39281–39294. DOI: https://doi.org/10.1007/s11356-022-18939-z

[4] Gereffi, G., Humphrey, J., Sturgeon, T., 2005. The Governance of Global Value Chains. Review of International Political Economy. 12(1), 78–104. DOI: https://doi.org/10.1080/09692290500049805

[5] Bozzola, M., Lamonaca, E., Santeramo, F.G., 2023. Impacts of Climate Change on Global Agri-Food Trade. Ecological Indicators. 154, 110680. DOI: https://doi.org/10.1016/j.ecolind.2023.110680

[6] Campiglio, E., Daumas, L., Monnin, P., et al., 2023. Climate-Related Risks in Financial Assets. Journal of Economic Surveys. 37(3), 950–992. DOI: https://doi.org/10.1111/joes.12525

[7] Su, Z., Deng, C., Feng, Y., et al., 2025. Climate Risks and Corporate Supply Chain Configuration: Evidence from China. Research in International Business and Finance. 76, 102852. DOI: https://doi.org/10.1016/j.ribaf.2025.102852

[8] Peres, R., Muller, E., Mahajan, V., 2010. Innovation Diffusion and New Product Growth Models: A Critical Review and Research Directions. International Journal of Research in Marketing. 27(2), 91–106. DOI: https://doi.org/10.1016/j.ijresmar.2009.12.012

[9] Pasquali, G., Krishnan, A., Alford, M., 2021. Multichain Strategies and Economic Upgrading in Global Value Chains: Evidence from Kenyan Horticulture. World Development. 146, 105567.

[10] Santeramo, F.G., Jeffliffe, J., Hoekman, B., 2024. Agri-Food Value Chains and the Global Food Dollar: The Role of Trade and Services. SSRN. DOI: https://dx.doi.org/10.2139/ssrn.4940299

[11] Zhang, D., Sun, Z., 2023. The Impact of Agricultural Global Value Chain Participation on Agricultural Total Factor Productivity. Agriculture. 13(11), 2151. DOI: https://doi.org/10.3390/agriculture13112151

[12] Beverelli, C., Gourevich, I., Heiland, I., et al., 2023. Trade and Welfare Effects of the WTO Trade Facilitation Agreement. World Trade Organization: Geneva, Switzerland. DOI: https://doi.org/10.30875/25189808-2023-4

[13] Barrett, C.B., Reardon, T., Swinnen, J., et al., 2022. Agri-Food Value Chain Revolutions in Low- and Middle-Income Countries. Journal of Economic Literature. 60(4), 1316–1377. DOI: https://doi.org/10.1257/jel.20201539

[14] Taglioni, D., Winkler, D., 2016. Making Global Value Chains Work for Development. The World Bank

Group: Washington, DC, USA. DOI: https://doi.org/10.1596/978-1-4648-0157-0

[15] Hair Jr., J.F., Hult, G.T.M., Ringle, C.M., et al., 2022. A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM), 3rd ed. SAGE: Thousand Oaks, CA, USA.

[16] Sarstedt, M., Liu, Y., 2024. Advanced Marketing Analytics Using Partial Least Squares Structural Equation Modeling (PLS-SEM). Journal of Marketing Analytics. 12, 1–5. DOI: https://doi.org/10.1057/s41270-023-00279-7

[17] Spoto, A., Nucci, M., Prunetti, E., et al., 2025. Improving Content Validity Evaluation of Assessment Instruments through Formal Content Validity Analysis. Psychological Methods. 30(2), 203–222.

[18] Kock, N., 2015. Common Method Bias in PLS-SEM: A Full Collinearity Assessment Approach. International Journal of e-Collaboration. 11(4), 1–10.

[19] Podsakoff, P.M., Podsakoff, N.P., Williams, L.J., et al., 2024. Common Method Bias: It's Bad, It's Complex, It's Widespread, and It's Not Easy to Fix. Annual Review of Organizational Psychology and Organizational Behavior. 11, 17–61. DOI: https://doi.org/10.1146/annurev-orgpsych-110721-040030

[20] Shmueli, G., Sarstedt, M., Hair, J.F., et al., 2019. Predictive Model Assessment in PLS-SEM: Guidelines for Using PLSpredict. European Journal of Marketing. 53(11), 2322–2347. DOI: https://doi.org/10.1108/EJM-02-2019-0189

[21] Henseler, J., Ringle, C.M., Sarstedt, M., 2016. Testing Measurement Invariance of Composites Using Partial Least Squares. International Marketing Review. 33(3), 405–431. DOI: https://doi.org/10.1108/IMR-09-2014-0304

[22] Chin, W.W., Dibbern, J., 2010. An Introduction to a Permutation Based Procedure for Multi-Group PLS Analysis: Results of Tests of Differences on Simulated Data and a Cross Cultural Analysis of the Sourcing of Information System Services Between Germany and the USA. In: Esposito Vinzi, V., Chin, W., Henseler, J., et al. (Eds.). Handbook of Partial Least Squares. Springer: Berlin/Heidelberg, Germany. pp. 171–193. DOI: https://doi.org/10.1007/978-3-540-32827-8_8

[23] Nitzl, C., Roldán, J.L., Cepeda, G., et al., 2016. Mediation Analysis in Partial Least Squares Path Modeling: Helping Researchers Discuss More Sophisticated Models. Industrial Management and Data Systems. 116(9), 1849–1864. DOI: https://doi.org/10.1108/IMDS-07-2015-0302

[24] Edeh, E., Lo, W.J., Khojasteh, J., 2023. Review of Partial Least Squares Structural Equation Modeling (PLS-SEM) Using R: A Workbook: By Joseph F. Hair Jr., G. Tomas M. Hult, Christian M. Ringle, Marko Sarstedt, Nicholas P. Danks, Soumya Ray. Cham, Switzerland: Springer, (2021). 197 pp. $0, Open Access; $59.99, Hardcover Book. Structural Equation Modeling: A Multidisciplinary Journal. 30(1), 165–167. DOI: https://doi.org/10.1080/10705511.2022.2108813

[25] Li, J., Shi, J., Cao, R., et al., 2024. How E-Commerce Can Boost China's High-Quality Agricultural Exports. Frontiers in Sustainable Food Systems. 8, 1372129. DOI: https://doi.org/10.3389/fsufs.2024.1372129

[26] Mi, J., 2023. The Impact of Food Standards on Export Quality in China: The Mediating Effect of TFP. Journal of the Faculty of Agriculture, Kyushu University. 68(1), 67–77. DOI: https://doi.org/10.5109/6770290