Indian Journal of Agricultural Economics 80: 3 (2025): 1020-1031
DOI:10.63040/25827510.2025.03.024

Trade-Environment-Agriculture Nexus in India: Evidence from Structural Equation Modelling

Keshav Soni, V. Sivasankar, and Ramadas Sendhil[1]

ABSTRACT

The intersection of trade liberalisation, environmental pressures, and domestic economic shifts is increasingly shaping the agricultural sector in India. This study provides SEM-based evidence on how trade and liberalisation policies under WTO frameworks interact with domestic economic factors and environmental conditions to influence agricultural value-added. It examines the period from 1995 to 2024 through a Structural Equation Modelling (SEM) framework that captures the complex, interdependent relationships among variables. The Final consumption expenditure contributes the most (68.6%), emphasising the role of rising domestic demand. The agricultural export share increases by 21.1%, reflecting the benefits of global market integration. Fertiliser use accounts for 15.8%, showing moderate but positive effects. Conversely, a rise in CO_2 emissions reduces agricultural value by 0.614%, underscoring the environmental trade-offs of growth. The novelty of this study lies in quantifying the trade–environment–agriculture nexus using standardised SEM paths. Policy recommendations emphasise promoting consumption-led growth, enhancing input efficiency, and aligning trade openness with environmental sustainability. These insights provide a timely foundation for designing climate-resilient and economically inclusive agricultural strategies that align with India's development and global commitments.

Keywords: WTO, international trade, agriculture, sustainability, climate change

JEL codes: C20, F13, O13, Q17, Q56

I
INTRODUCTION

The intersection of trade liberalisation, economic growth, and environmental sustainability represents a critical challenge for developing economies, particularly in the Global South (Anderson & Nelgen, 2013; Winters et al., 2004). In India, where agriculture employs approximately 50% of the workforce and contributes significantly to GDP (Ministry of Agriculture & Farmers Welfare, 2025), navigating these competing priorities has become increasingly complex following the country's integration into the World Trade Organisation (WTO) framework in 1995. The liberalisation of agricultural trade under WTO agreements has created new market opportunities while simultaneously introducing environmental and social vulnerabilities (Blandford et al., 2011; Winters et al., 2004). These changes have particularly affected smallholder farmers, who account for 86% of India's farming population but face constraints in accessing technology, credit, and market infrastructure (Chand et al., 2011; FAO, 2021). The resulting intensification of agricultural production has led to increased fertiliser use and environmental degradation, raising concerns about long-term sustainability (Pingali, 2012).

Existing literature has broadly examined trade liberalisation, environmental impacts, and agricultural productivity in isolation (Frankel & Rose, 2005). While

[1]Pondicherry University, Puducherry, India.

some studies have explored bilateral relationships, such as trade-environment linkages (Antweiler et al., 2001) or environment-productivity connections (Auffhammer et al., 2012), few have employed a comprehensive systems approach that captures the complex interdependencies among these variables simultaneously. This study addresses this gap using Structural Equation Modelling (SEM) to analyse the individual and interactive relationships among trade openness, environmental pressures, and agricultural outcomes in India. Unlike conventional regression approaches, SEM enables the decomposition of effects across multiple pathways, providing a more nuanced understanding of how policy interventions transmit through economic and environmental channels (Bollen, 1989; Kline, 2023).

This study pursues three primary objectives: first, to examine how trade liberalisation, operationalised through India's WTO engagement, affects agricultural value added, building on previous work by Pursell et al. (2009) and Gulati & Banerjee (2015). Second, to assess the mediating roles of key variables, including fertiliser use intensity, per capita CO_2 emissions, and consumption expenditure share in GDP, extending the analytical framework developed by Copeland & Taylor (2013) and Porter & Van Der Linde (1995). Third, to contribute to integrated policy design by identifying specific pathways through which trade and environmental policies interact to influence agricultural sustainability, addressing calls for more holistic approaches in agrarian economics (Pretty et al., 2018; Rockström et al., 2017).

The analysis employs annual time-series data spanning 1995-2020, utilising SEM to model complex interrelationships among observed variables: agricultural export share, fertiliser use intensity, CO_2 emissions per capita, consumption expenditure share in GDP, and agricultural value added. This methodological approach follows best practices established by Hair et al. (2017) and enables simultaneous estimation of multiple relationships while accounting for measurement error and unobserved heterogeneity. This research makes several significant contributions to the literature. Methodologically, it represents one of the few applications of SEM to Indian agricultural trade and environmental data, providing a template for similar analyses in other developing economies (Ritu & Kaur, 2024). Empirically, it offers new insights into how trade liberalisation affects agricultural sustainability, with particular attention to vulnerable farming communities. Theoretically, it advances understanding of trade-environment-agriculture linkages by demonstrating how these relationships operate simultaneously rather than in isolation.

The findings are expected to inform evidence-based policy interventions that balance productivity enhancement with environmental stewardship, particularly relevant as India pursues ambitious climate commitments under the Paris Agreement while maintaining agricultural growth targets. In the context of ongoing debates about sustainable development goals and climate-resilient agriculture, this study provides timely evidence for policymakers seeking to reconcile trade ambitions with environmental objectives (IPCC, 2022; United Nations, 2015). By identifying specific pathways through which liberalisation affects agricultural outcomes, the research contributes to designing integrated policies promoting economic growth and environmental sustainability in developing country contexts.

II
DATA AND METHODOLOGY

This study utilises annual country-level panel data obtained from the World Development Indicators (WDI) of the World Bank, covering macroeconomic, environmental, and trade-related variables for developing countries from 1995 to 2024. The variables are of *I(1)* order. The primary objective is to examine the structural impact of WTO-related trade liberalisation and domestic factors on agricultural performance. The dependent variable is the agricultural value added to GDP. The model includes four key explanatory variables. Their definitions are listed in Table 1.

TABLE 1. DESCRIPTION OF VARIABLE

Variable Name	Definition	Unit	Source
Agricultural Value Added (AVA)	Agriculture, forestry, and fishing value added as a share of GDP	% of GDP	WDI
Final Consumption Expenditure (FCE)	Final consumption expenditure as a share of GDP	% of GDP	WDI
Fertiliser Use Ratio (FUR)	Fertiliser consumption as a percentage of fertiliser production	%	WDI
Agricultural Export Share (AES)	Agricultural raw materials exports as a share of merchandise exports	%	WDI
Carbon Emissions (Ln_CO_2)	Total carbon dioxide (CO_2) emissions excluding LULUCF, natural log transformed	$MtCO_2e$	WDI

The structural equation modelling (SEM) framework is adopted in this study to assess the simultaneous influence of multiple observed variables on agricultural value added (Gujarati & Porter, 2009). Model identification is ensured by specifying a recursive system with more knowns than unknowns, as all variables are observed variables in this scenario. The model is estimated using maximum likelihood estimation (MLE), assuming multivariate normality and adequate sample size. Unlike conventional regression models, SEM provides the advantage of estimating complex interrelationships between explanatory variables and the outcome variable within a unified model structure.

$$AVA_t \leftarrow \lambda_1 AES_t + \lambda_2 Log\_CO_{2t} + \lambda_3 FCE_t + \lambda_4 FUR_t + \zeta_t \quad (1)$$

In equation (1), the coefficients λ_1 to λ_5 are structural path coefficients. ζ_t measures the structural error. All predictor variables are treated as observed endogenous or exogenous variables in the structural framework (Kline, 2023). Although the current specification does not involve latent constructs or observed indirect effects, the SEM framework enables the examination of direct structural pathways from policy-related and environmental variables, such as fertiliser use, carbon emissions, trade orientation, and consumption expenditure, to agricultural value added. Each structural path is estimated with robust standard errors to address potential heteroscedasticity in the model (Bollen, 1989). Figure 1 illustrates the hypothesised structural relationships among the study variables. Single-headed arrows represent directional causal paths, with standardised coefficients estimated using robust SEM. All relationships are grounded in theoretical assumptions linking export share, consumption patterns, environmental pressure, and agricultural value added. Effect decomposition confirms that the relationships operate predominantly through direct effects, aligning with the theoretical expectation that trade and environmental variables influence agricultural performance relatively straightforwardly.

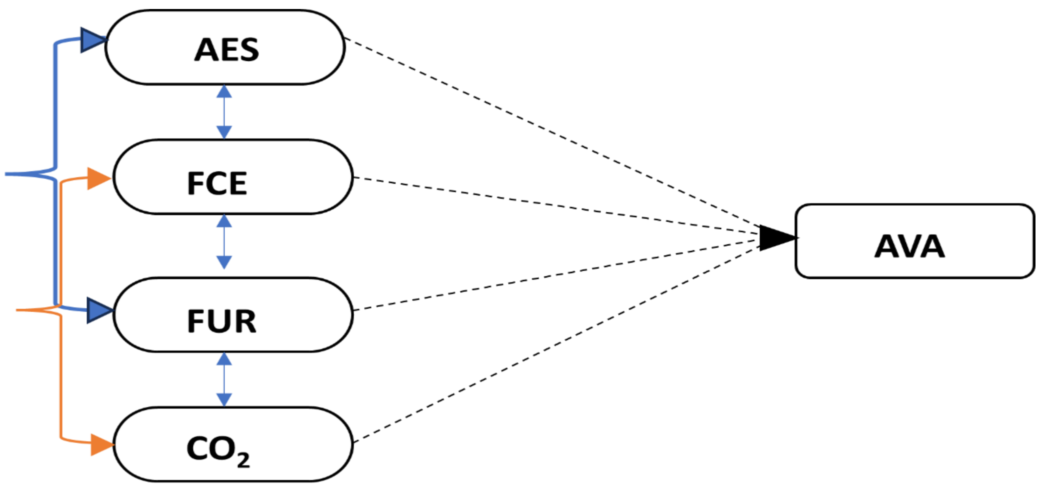

FIGURE 1. PATH DIAGRAM

Several diagnostic and goodness-of-fit tests were employed to ensure the robustness and reliability of the SEM specification (Li et al., 2018). Model fit was evaluated using multiple indicators:

- Equation-level R^2
- Correlation Coefficient (mc) and its square (mc^2)
- Coefficient of Determination (CD)
- Standardised Root Mean Square Residuals (SRMR)

These findings (presented in Table 6) suggest a structural model that fits well overall, exhibits excellent internal consistency, and shows slight estimation bias. An inadequate model fit would jeopardise important econometric attributes, including consistency, efficiency, and the objectivity of estimates. Insufficient fit in SEM can lead to erroneous inference paths, skewed coefficient loadings, and unstable structural relationships. As a result, the provided fit metrics confirm the technical soundness and robustness of the designated model.

III
RESULTS AND DISCUSSION

3.1 Descriptive Statistics

Table 2 offers essential information on India's agricultural and environmental framework concerning sustainable growth and WTO-led liberalisation. Although low on average, the Agricultural Export Share (AES) varies significantly, reflecting changes in trade performance resulting from WTO reforms. Anderson & Martin (2005) also endorse the same argument. In particular, WTO-mandated export subsidy reductions restrict direct government assistance to exporters, forcing domestic companies to increase their competitiveness in international markets. India's capacity to expand agricultural exports has been impacted by this shift, especially in price-sensitive commodities. Blandford et al. (2011) suggested this argument due to the WTO's compliance requirements.

The sector's GDP contribution, measured by Agricultural Value Added (AVA), has modest dispersion, which aligns with India's structural shift away from agriculture and toward higher-productivity industries. The steady and comparatively high Final Consumption Expenditure (FCE) underscores the tenacity of a consumption-driven growth strategy, a point also widely discussed by Panagariya (2008). The wide variation in the Fertiliser Use Ratio (FUR), used here as a proxy for agricultural capital investment, reflects uneven patterns of input intensification across regions. Gulati & Banerjee (2015) suggest low urea prices as a primary source of intensification and imbalances. This illustrates India's continuous attempts to ensure sufficient agricultural investment while bringing domestic input subsidies into compliance with WTO regulations. Hoda & Gulati (2007) argue that the disagreement of developing countries arises due to a lack of focus on special and differential treatment clauses, causing uproar at WTO summits.

TABLE 2. RESULTS OF DESCRIPTIVE STATISTICS

Statistic	AES	AVA	FCE	FUR	LN_CO2
Mean	1.65	18.60	70.74	146.05	7.37
Median	1.49	17.09	70.30	149.48	7.43
Maximum	4.10	25.20	76.18	188.97	7.99
Minimum	0.82	16.03	65.62	113.40	6.68
Std. Dev.	0.69	2.93	3.37	21.52	0.42
Skewness	1.71	1.17	0.17	0.12	-0.18
Kurtosis	6.57	2.84	1.77	1.99	1.53
Jarque-Bera	30.51	6.90	2.04*	1.35*	2.85*

Source: Authors' Calculation
Note: * if p-value > 0.05

Finally, even after logarithmic adjustment, a minor asymmetry remains in the distribution of carbon emissions (Ln_CO2), suggesting inefficient energy consumption and the environmental trade-offs associated with economic progress.

3.2 Pairwise Correlation Coefficients

Table 3 presents a pairwise correlation matrix that reveals meaningful relationships, complementing the descriptive patterns observed in Table 2. The significant negative correlation of approximately 38% between Agricultural Export Share (AES) and Final Consumption Expenditure (FCE) suggests that agricultural export orientation decreases as domestic consumption increases, possibly due to inward-focused growth dynamics or a decrease in surplus availability for international markets. In the same way, despite liberalisation efforts, the poor integration of India's agricultural output into global value chains is highlighted by the weak and statistically negligible link between AES and other variables, such as Agricultural Value Added (AVA) and carbon emissions. AVA and FCE show a significant positive correlation (78%), supporting the notion that consumption-led growth is supported by increasing agricultural output, as Panagariya (2008) suggested.

Its negative correlation with the Fertiliser Use Ratio (-71%), however, suggests that there may be a trade-off between increasing consumption and investing in agricultural capital, possibly due to changes in WTO regulations that reorganised input subsidies. Additionally, there is a negative correlation between AVA and FUR (-67%), suggesting that efficiency issues may arise since a greater reliance on fertiliser inputs does not always result in equal value addition. AVA and Ln_CO2 show the most significant inverse connection (-83%), indicating that agricultural growth has not been carbon-intensive, most likely because low-emission practices or under-mechanisation have persisted as implicated by Antweiler et al. (2001). Conversely, a 64% positive correlation between FUR and carbon emissions suggests that rising emissions are typically associated with higher input intensification. WTO-compliant market reforms may unintentionally reinforce this trend by altering investment behaviour.

TABLE 3. PAIRWISE CORRELATIONS

Variables	(1)	(2)	(3)	(4)	(5)
(1) AES	1.000				
(2) FCE	-0.378*	1.000			
	(0.039)				
(3) AVA	-0.015	0.783*	1.000		
	(0.936)	(0.000)			
(4) FUR	0.269	-0.714*	-0.667*	1.000	
	(0.150)	(0.000)	(0.000)		
(5) Ln_CO_2	0.015	-0.471*	-0.834*	0.638*	1.000
	(0.939)	(0.009)	(0.000)	(0.000)	

Source: Authors' Calculation.
Values in () are p-values. * Signifies p-value < 0.05.

3.3 Direct Effect Assessment Using Simultaneous Equation Model

The structural equation model results (Table 4 and Figure 2) provide standardised coefficients illuminating the complex pathways through which various factors influence agricultural value addition in India's post-liberalisation context. The most substantial positive effect is in Final Consumption Expenditure (FCE), with a coefficient of 68.6%. This finding implies that enhanced domestic consumption, driven by rising incomes, expanding rural demand, and improved market integration, constitutes the primary determinant of agricultural value addition. Sen's (1999) "Development as freedom" favoured this consumption-led growth in the case of equal distribution of resources. This outcome aligns with Keynesian theoretical perspectives, which posit that consumption demand serves as the principal driver of output growth (Helpman & Krugman, 1985). Within the WTO framework, liberalisation has enhanced market access and facilitated consumer-oriented transformations, potentially augmenting domestic demand for agricultural products through improved supply chains and reduced transaction costs.

The Agricultural Export Share (AES) has a positive correlation with agricultural performance, contributing 21.1% to value addition. This coefficient highlights how trade integration enhances market incentives and competitiveness by exposing firms to international price signals and quality standards. India has progressively aligned its trade policies with WTO standards, including reduced export restrictions and enhanced logistics infrastructure, which benefited agricultural producers by expanding access to global markets. This finding supports traditional trade theories that emphasise efficiency gains from specialisation and external market participation, consistent with the principle of comparative advantage.

The Fertiliser Use Ratio (FUR), representing input intensification and capital investment, accounts for 15.8% of agricultural value addition. While this positive coefficient confirms the contribution of productive inputs to yield enhancement, the relatively modest magnitude suggests that capital deepening alone is insufficient for substantial productivity gains. This finding raises concerns regarding regional disparities in input access, inefficient subsidy targeting mechanisms, and diminishing marginal returns to fertiliser application, challenges that WTO provisions on domestic support and subsidy disciplines increasingly seek to address through Aggregate Measurement of Support (AMS).

Conversely, CO_2 emissions (Ln_CO2) exhibit a substantial and statistically significant negative impact on agricultural productivity. Given the logarithmic transformation, the interpretation indicates that agricultural value-added decreases by 0.614 percentage points for every 1% increase in per capita CO_2 emissions. This finding highlights the adverse effects of carbon-intensive practices on climate-sensitive sectors such as agriculture, emphasising the environmental trade-offs inherent in development. The negative coefficient also suggests a potential misalignment between environmental sustainability objectives and growth strategies, a challenge that current WTO frameworks inadequately address due to the limited integration of environmental considerations into trade rules. This relationship highlights the importance of developing climate-resilient agricultural policies to maintain productivity while reducing carbon emissions.

TABLE 4. ESTIMATES OF STRUCTURAL SEM FRAMEWORK

Standardized	Coefficient	Std. Error	P>z
AES	0.211***	0.040	0.000
Ln_CO_2	-0.614***	0.058	0.000
FUR	0.158***	0.063	0.011
FCE	0.686***	0.062	0.000
cons	1.044	1.185	0.378

Source: Author's Calculation
*** p<0.01, ** p<0.05, * p<0.1

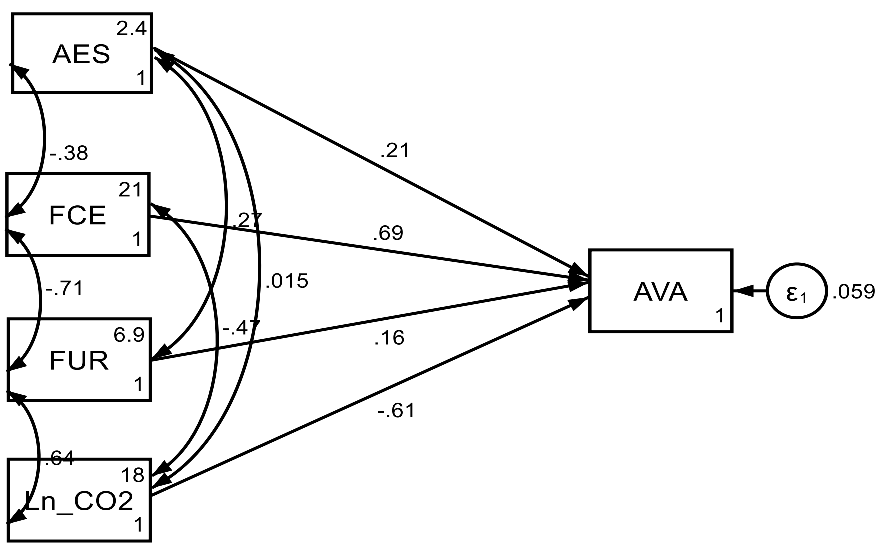

FIGURE 2: PATH ANALYSIS RESULTS

3.4 *Interaction Effects of Variables*

The SEM result, which indicates that fertiliser use has a positive and significant impact on agricultural value added, is supported by the positive and significant interaction effect between the agri-export share and the fertiliser use ratio (0.269), as shown in Table 5. This supports the claim that trade liberalisation encourages input-intensive farming methods through export orientation, which aligns with the structural logic of the SEM and more general liberalisation theory assumptions. The observed trade-off between trade expansion and domestic welfare indicators in the SEM is evident in the negative and substantial covariance between the agri-export share and the consumption share in GDP (-0.378). It raises questions about food security and inclusivity by suggesting a possible displacement effect, in which export-related advantages may not be effectively converted into benefits for broader consumption. The SEM's environmental cost patterns, which show a correlation between emissions and agricultural intensification, are further supported by the significant positive covariance between carbon emissions and fertiliser use ratio (0.638). The SEM's indication that growth based on consumption may be less environmentally burdensome is consistent with the negative covariances involving the consumption share, both with emissions (-0.471) and the fertiliser use ratio (-0.714). In addition to providing extra internal consistency and complementing the SEM path estimates, these covariances also highlight inter-variable conflicts and support the policy trade-offs between sustainability, trade, and growth. The need for sophisticated WTO-era agriculture policies that strike a balance between export incentives, inclusive consumption, and environmental protections is highlighted by this complementarity.

TABLE 5. RESULTS OF INTERACTION EFFECT MATRIX

Standardized	Coefficient	Std. Error	z	P>z
AES, Ln_CO_2	0.015	0.160	0.090	0.927
AES, FUR	0.269**	0.114	2.370	0.018
AES, FCE	-0.378***	0.120	-3.160	0.002
Ln_CO_2, FUR	0.638***	0.090	7.080	0.000
Ln_CO_2, FCE	-0.471***	0.125	-3.770	0.000
FUR, FCE	-0.714***	0.097	-7.350	0.000

Source: Author's Calculation
**** $p<0.01$, ** $p<0.05$, * $p<0.1$*

3.5 Robustness Checks

The high fit and dependability of the calculated SEM model are confirmed by numerous robustness assessments presented in Table 6.

TABLE 6. ROBUSTNESS CHECKS

Fit Statistic	Value	Description
Equation-level R-squared	0.941	Proportion of variance in *AVA* explained by the model
Correlation (mc)	0.970	Correlation between the dependent variable and its predicted value
Squared Correlation (mc^2)	0.941	Bentler–Raykov squared multiple correlation coefficient
Standardised Root Mean Square Residual (SRMR)	0.000	Absolute average discrepancy between observed and predicted correlations (high R^2/CD values indicate excellent model fit)
Coefficient of Determination (CD)	0.941	Overall proportion of variance explained across all equations
Mean VIF	1.99	The mean VIF is below the standard threshold of 5, indicating no serious multicollinearity among the predictors.

Source: Author's Calculation

The strong correlation between actual and predicted outcomes indicates that linkages are accurately specified, and the high explanatory power at the equation level suggests that the model accounts for nearly all significant variance in agricultural value added. The internal coherence of the model is further supported by the squared multiple correlation coefficient, which increases trust in the identified structural relationships. Furthermore, there is almost no difference between the observed and predicted associations. This is uncommon and indicates a well-specified model, as indicated by the SRMR value, which is a crucial measure of model fit. The model consistently performs well across all equations, as confirmed by the coefficient of determination. When combined, these findings provide compelling evidence that the SEM framework is both conceptually sound and statistically robust.

IV
CONCLUSION

This study examined the impact of trade and policy liberalisation under the WTO framework on agricultural productivity in India, specifically through its interaction with domestic economic factors and environmental pressures. Using Structural Equation Modelling (SEM) on annual time-series data, we demonstrated the interconnected roles of agricultural exports, fertiliser use, CO_2 emissions, and consumption expenditure in shaping agricultural value added. The model revealed statistically significant direct effects of trade and input use on productivity and highlighted indirect pathways mediated by environmental externalities. This systems-level approach allowed us to meet the study's core objectives, evaluating the impact of trade liberalisation, understanding the role of mediating variables, and providing a holistic picture of the trade-environment-agriculture nexus.

The results underscore the importance of aligning trade policies with sustainable input use and environmental safeguards. Policy coherence between global trade obligations and local ecological realities becomes crucial for a country like India, where smallholders and resource-poor farmers dominate the agricultural landscape. Our findings suggest that future trade strategies should embed sustainability metrics and support mechanisms for environmental resilience at the farm level. Despite the robust modelling approach, the study has limitations, including the exclusion of disaggregated regional dynamics and a focus on a limited set of variables due to data availability. Future research could extend this analysis by incorporating spatial dimensions, broader environmental indicators, and more granular economic policy instruments. Nevertheless, this work makes a significant contribution to the empirical literature and provides actionable insights for achieving climate-resilient agricultural development under liberalised trade regimes.

REFERENCES

Anderson, K., & Martin, W. (2005). Agricultural trade reform and the Doha Development Agenda. *World Economy, 28*(9), 1301–1327. https://doi.org/10.1111/j.1467-9701.2005.00735.x

Anderson, K., & Nelgen, S. (2013). *Updated national and global estimates of distortions to agricultural incentives, 1955 to 2011*. World Bank.

Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment? *American Economic Review, 91*(4), 877–908. https://doi.org/10.1257/aer.91.4.877

Auffhammer, M., Ramanathan, V., & Vincent, J. R. (2012). Climate change, the monsoon, and rice yield in India. *Climatic Change, 111*(2), 411–424. https://doi.org/10.1007/s10584-011-0208-4

Blandford, D., Brink, L., Josling, T. E., & Orden, D. (2011). *WTO disciplines on agricultural support: Experience to date and assessment of Doha proposals.* International Food Policy Research Institute (IFPRI).

Bollen, K. (1989). *Structural equations with latent variables.* John Wiley & Sons.

Chand, R., Lakshmi Prasanna, P. A., & Singh, A. (2011). Farm size and productivity: Understanding the strengths of smallholders and improving their livelihoods. *Economic & Political Weekly, 46*(27).

Copeland, B. R., & Taylor, M. S. (2013). *Trade and the environment: Theory and evidence.* Princeton University Press.

FAO. (2021). *The state of food and agriculture 2021: Making agrifood systems more resilient to shocks and stresses.* FAO. https://doi.org/10.4060/cb4476en

Frankel, J. A., & Rose, A. K. (2005). Is trade good or bad for the environment? Sorting out the causality. *The Review of Economics and Statistics, 87*(1), 85–91. https://doi.org/10.1162/0034653053327577

Gujarati, D. N., & Porter, D. C. (2009). *Basic econometrics* (5th ed.). McGraw-Hill/Irwin.

Gulati, A., & Banerjee, P. (2015). *Rationalising fertiliser subsidy in India: Key issues and policy options* (Working Paper No. 307). Indian Council for Research on International Economic Relations (ICRIER).

Helpman, E., & Krugman, P. R. (1985). *Market structure and foreign trade: Increasing returns, imperfect competition, and the international economy.* MIT Press.

Hoda, A., & Gulati, A. (2007). *WTO negotiations on agriculture and developing countries.* Johns Hopkins University Press.

IPCC. (2022). *Climate change 2022: Impacts, adaptation and vulnerability.*

Kline, R. B. (2023). *Principles and practice of structural equation modeling* (5th ed.). Guilford Publications.

Li, W., Wei, X., Zhu, R., & Guo, K. (2018). Study on factors affecting the agricultural mechanization level in China based on structural equation modeling. *Sustainability, 11*(1), 51. https://doi.org/10.3390/su11010051

Ministry of Agriculture & Farmers Welfare. (2025). *Annual report 2024–25.* Government of India.

Pingali, P. L. (2012). Green revolution: Impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences, 109*(31), 12302–12308. https://doi.org/10.1073/pnas.0912953109

Porter, M. E., & Van Der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives, 9*(4), 97–118. https://doi.org/10.1257/jep.9.4.97

Pretty, J., Benton, T. G., Bharucha, Z. P., Dicks, L. V., Flora, C. B., Godfray, H. C. J., Goulson, D., Hartley, S., Lampkin, N., Morris, C., Pierzynski, G., Prasad, P. V. V., Reganold, J., Rockström, J., Smith, P., Thorne, P., & Wratten, S. (2018). Global assessment of agricultural system redesign for sustainable intensification. *Nature Sustainability, 1*(8), 441–446. https://doi.org/10.1038/s41893-018-0114-0

Ritu, R. K., & Kaur, A. (2024). Unveiling Indian farmers' adoption of climate information services for informed decision-making: A path to agricultural resilience. *Climate and Development.* https://doi.org/10.1080/17565529.2024.2409774

Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., Wetterstrand, H., DeClerck, F., Shah, M., Steduto, P., de Fraiture, C., Hatibu, N., Unver, O., Bird, J., Sibanda, L., & Smith, J. (2017). Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio, 46*(1), 4–17. https://doi.org/10.1007/s13280-016-0793-6

Sen, A. (1999). *Development as freedom.* Oxford University Press.

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development.*

Winters, L. A., McCulloch, N., & McKay, A. (2004). Trade liberalization and poverty: The evidence so far. *Journal of Economic Literature, 42*(1), 72–115. https://doi.org/10.1257/002205104773558056