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Agricultural carbon sequestration and supply chain resilience: Evidence from large language models and multimodal data

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Abstract

Against the backdrop of intensifying climate change, more frequent extreme weather events, and rising volatility in agricultural product markets, enhancing the resilience of agricultural supply chains has become a critical issue for safeguarding food security, farmers' livelihoods, and the green transition. In response, this paper integrates large language models, multimodal remote sensing data, and causal machine learning methods to identify the effects of agricultural carbon sequestration on supply chain resilience and the mechanisms through which these effects operate. Specifically, the paper employs large language models to conduct semantic parsing and knowledge extraction from policy documents, corporate ESG disclosures, and local government work reports, thereby identifying key variables such as the intensity of low-carbon governance, the degree of supply chain coordination, characteristics of risk exposure, and institutional response capacity. Combined with remote sensing and geospatial information, the study measures regional agricultural carbon sequestration potential, land-use change, and ecosystem stability, and on this basis constructs an indicator system for agricultural supply chain resilience. In terms of identification strategy, the paper applies double machine learning and heterogeneous treatment effect methods to estimate the average and distributional effects of agricultural carbon sequestration on supply chain resilience, while also using complex network analysis to reveal the mechanisms through which risk shocks propagate and are mitigated among supply chain actors. With respect to the underlying mechanisms, this paper focuses on examining whether agricultural carbon sequestration enhances production resilience through the diffusion of green technologies, the optimisation of resource allocation, and improvements in ecological stability; whether it improves contractual relationships and information transparency through low-carbon certification, green preferences, and digital governance, thereby strengthening circulation resilience and organisational resilience; and whether it alleviates financing constraints, reinforces benefit-sharing arrangements, and enhances overall recovery capacity and adaptability through ecological compensation, carbon incentives, and local policy responses. From the perspectives of multimodal data integration and causal identification, this paper extends the research frontier on the economic consequences of agricultural carbon sequestration and provides empirical evidence for the development of multifunctional agricultural ecosystems.

Keywords: Agricultural carbon sequestration, climate shocks, double machine learning, multimodal data fusion, supply chain resilience

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