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Frugal Innovation in the Relationship Between Eco-Innovation and Green Manufacturing

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Introdução

The increasing global emphasis on environmental sustainability has compelled manufacturing firms to pursue innovation strategies that mitigate ecological impacts while sustaining competitiveness (El Samad, 2024; Liu et al., 2023). Eco-innovation embeds sustainability principles in products and processes, while green manufacturing optimizes resource use and minimizes waste for efficiency and compliance (Chen & Cao, 2025; Haleem et al., 2023). Yet high costs and technical barriers constrain adoption in resource-limited contexts.

Problema de Pesquisa e Objetivo

Despite growing interest, integrated empirical analyses of eco-innovation, frugal innovation, and green manufacturing across development levels remain scarce. This study asks: What role does frugal innovation play in the eco-innovation–green manufacturing relationship in developed (Germany, USA) versus developing (Brazil, India) contexts? Objectives are to (i) assess eco-innovation's direct effect on green manufacturing and (ii) evaluate frugal innovation's moderating influence across both contexts.

Fundamentação Teórica

Eco-innovation integrating environmental sustainability into processes and product design to reduce ecological impact and boost performance (Hojnik & Ruzzier, 2016; Kesidou & Demirel, 2012). Green manufacturing targets waste reduction, pollution control, and resource optimization throughout product lifecycles (Gopal et al., 2021; Haleem et al., 2023) . Frugal innovation, marked by affordability, simplicity, and local resource use, lowers financial and technical barriers, complementing eco-innovation to broaden sustainable practice adoption (Weyrauch & Herstatt, 2016; Hossain et al., 2021).

Metodologia

An online survey gathered data from 303 manufacturing executives in Brazil, India, Germany, and the USA. Frugal innovation was measured via Rossetto et al.'s (2023) scale; eco-innovation and green manufacturing scales were adapted from Hsu et al. (2016) and Testa & Iraldo (2010). Data were analyzed using PLS-SEM in SmartPLS 4 to evaluate measurement and structural models, followed by Multi-Group Analysis (MGA) to compare developed and developing contexts (Hair et al., 2022; Sarstedt et al., 2011).

Análise dos Resultados

Eco-innovation strongly predicted green manufacturing ($\beta = 0.778$; $p < 0.001$), and frugal innovation also had a positive effect ($\beta = 0.208$; $p < 0.001$). Frugal innovation moderated the eco-innovation–green manufacturing link positively ($\beta = 0.096$; $p = 0.016$) . MGA showed no significant differences between developed and developing groups across hypotheses ($p > 0.05$). The model explained 78 % of variance in green manufacturing ($R^2 = 0.780$).

Conclusão

This study demonstrates that eco-innovation and frugal innovation jointly enhance green manufacturing regardless of a country's development level. Frugal innovation reduces cost and complexity, amplifying eco-innovation's impact under diverse resource conditions. An integrated eco-frugal approach thus provides a viable pathway for firms to implement sustainable manufacturing practices across both developed and developing environments.

Contribuição / Impacto

Theoretically, this work extends sustainable innovation literature by empirically validating frugal innovation's role in strengthening eco-innovation's effect on green manufacturing (El Samad, 2024; Liu et al., 2023). Managerially, it guides executives to combine frugal and eco-innovative practices to overcome adoption barriers. For policymakers, it supports designing incentives and programs that foster low-cost, resource-efficient innovations aligned with SDG 9.5 and 12.a, promoting inclusive and resilient industrial development.

Referências Bibliográficas

El Samad (2024); Liu et al. (2023); Chen & Cao (2025); Haleem et al. (2023); Levänen et al. (2022); Weyrauch & Herstatt (2016); Hossain et al. (2021); Rossetto et al. (2023); Hsu et al. (2016); Testa & Iraldo (2010).