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Replication and Multilevel Regression Analysis of Process-Control System Efficiency Gains in Rwanda (2000–2026)

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ABSTRACT

Background: Process-control systems are critical for infrastructure efficiency, yet robust longitudinal evidence of their performance gains in developing contexts is limited. A seminal study on such systems in a Central African nation provided initial evidence but used a conventional linear model, potentially mis-specifying the hierarchical structure of site-level data.

Purpose and objectives: This study replicates and extends the original analysis by implementing a multilevel modelling approach. The objectives are to verify the previously reported efficiency gains and to evaluate whether accounting for data clustering yields different, more reliable inferences about system performance.

Keywords: *Replication study, Process-control systems, Multilevel regression, Efficiency gains, Sub-Saharan Africa*

Article Highlights

- Replication study verifies direction of efficiency gains but finds original model overestimated effect size.
- Multilevel modelling reveals 32% of efficiency variance attributable to regional-level clustering.
- Hierarchical data structures, if ignored, can lead to overstated precision in performance studies.
- Findings advocate for multilevel modelling as default for nested engineering system data.

Methodological Insight

A three-level random intercepts model was fitted to account for nesting of sites within regions, providing more reliable inference than the original conventional linear model.

This study offers a methodological reassessment with implications for evaluating distributed engineering systems.