Title: The asymmetric influence of quadra-procyclicality on energy innovation

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Abastact: The urgency of global climate commitments and sustainable energy transitions has elevated energy innovation to the forefront of economic policy discourse. Understanding the cyclical dynamics that shape energy innovation becomes critically important for effective policy design. This study examines the impact of quad-procyclicality encompassing fiscal, financial, energy consumption, and carbon emission procyclicality on energy innovation across 23 OECD countries from 2003 to 2022. Building on emerging evidence that economic cycles fundamentally alter innovation trajectories, we introduce a novel comprehensive framework that simultaneously considers four distinct but interconnected cyclical patterns. Energy innovation is crucial for addressing energy and climate-related challenges through the promotion of cleaner and more efficient technologies. Our cointegration analysis reveals long-run relationships between all types of procyclicality and energy innovation. While Driscoll-Kraay linear regression estimates indicate positive effects of all procyclicalities on energy innovation, panel quantile regression with non-additive fixed effects demonstrates that financial procyclicality is negatively associated with energy innovation. Moreover, the impact of quad-procyclicality is more pronounced at higher quantiles of innovation output. Our results further show that financial procyclicality decreases energy innovation by reducing financial efficiency. However, this negative effect can be mitigated by a stable financial system. These findings have profound implications for designing cycle-sensitive policies that maximize innovation outcomes while minimizing the adverse effects of economic volatility. Policymakers should implement targeted, cycle-sensitive strategies that leverage the positive effects of fiscal, energy consumption, and carbon emission procyclicality on energy innovation, while mitigating the negative impacts of financial procyclicality, particularly during economic expansions and for high-impact innovations.

Keyword: Energy innovation ,Fiscal procyclicality, Energy procyclicality, Carbon procyclicality, Financial procyclicality, Quantile regression

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