# 1.2 Problem Statement

Boardroom narratives increasingly portray fully autonomous, self‑optimising supply chains as an imminent reality. Capital expenditure on robotics and digital platforms has surged—global robot installations have more than trebled since 2014¹—yet objective performance indicators tell a less decisive story. Across OECD economies, labour‑productivity growth slowed sharply after 2020 and was effectively flat in 2021, despite the steepest wave of automation investment in a generation.² This divergence suggests that hardware deployment alone is insufficient; value is unlocked only when data orchestration, process redesign and workforce capabilities mature in tandem.

Evidence from industry surveys reinforces the execution gap. Almost 70 per cent of manufacturers admit that digital pilots stall before reaching scale, a phenomenon widely labelled “pilot purgatory.”³ Where projects do advance, they seldom integrate the full span of the supply network, leaving critical links—tier‑two suppliers, contract logistics providers or aftermarket service hubs—outside the real‑time data loop. Scholarly meta‑analyses likewise highlight a dearth of longitudinal datasets that track operational efficiency, resilience metrics and environmental intensity within the same firm, making it difficult to verify whether the promised triple win of speed, cost and sustainability is materialising.

The environmental dimension is especially ambiguous. Reports from the Global Lighthouse Network cite average productivity gains of 30–90 per cent in digitally mature plants, alongside defect reductions approaching one half, yet they provide only snapshot carbon figures and seldom reveal full scopes 1–3 footprints.⁴ Recent econometric work even detects “energy rebound” effects whereby higher equipment utilisation erodes the energy savings expected from smart‑factory investments.⁵ Without robust counterfactual analysis, it remains unclear whether Industry 4.0 genuinely accelerates progress toward science‑based climate targets or merely redistributes emissions along the value chain.

Sectoral heterogeneity further complicates the picture. Logistics operators prioritise real‑time visibility and last‑mile automation; consumer‑goods firms emphasise digital traceability and demand sensing; automotive incumbents focus on flexible, robot‑dense body shops. Because each path combines unique technology bundles and legacy constraints, lessons learned in one sector cannot be applied wholesale to another. Cross‑case studies that compare operational and sustainability outcomes under varying organisational and technological conditions are therefore essential.

The central problem addressed in this thesis is the paucity of empirically grounded, multi‑dimensional evidence on whether Industry 4.0 initiatives deliver concurrent gains in supply‑chain performance and sustainability—and under what circumstances those gains persist. By constructing a decade‑long panel for three publicly traded leaders with rich operational and ESG disclosures, and by applying interrupted time‑series and frontier‑efficiency techniques, this study aims to quantify the magnitude, timing and durability of any benefits while exposing the residual gaps that still impede scalable value creation.

## Footnotes

1. International Federation of Robotics, World Robotics 2024: Executive Summary (Frankfurt: IFR, 2024). https://ifr.org/img/worldrobotics/Executive\_Summary\_WR\_2024\_Industrial\_Robots.pdf

2. OECD, Compendium of Productivity Indicators 2023 (Paris: OECD, 2023). https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/02/oecd-compendium-of-productivity-indicators-2023\_bdbeba7d/74623e5b-en.pdf

3. Manufacturing Leadership Council, “Scaling in the Fourth Industrial Revolution,” 2023. https://manufacturingleadershipcouncil.com/scaling-in-the-fourth-industrial-revolution-35036/

4. World Economic Forum, Global Lighthouse Network: Shaping the Next Chapter of the Fourth Industrial Revolution (Geneva: WEF, 2023). https://www3.weforum.org/docs/WEF\_Global\_Lighthouse\_Network\_2023.pdf

5. J. Chen et al., “Industrial Automation and the Energy Rebound Effect in China,” Energy 300 (2025). https://www.sciencedirect.com/science/article/abs/pii/S0360544225021243