

THE DIGITAL DIVIDE IN GREEN LOGISTICS TRANSFORMATION: WHY INDUSTRY 4.0 BENEFITS LARGE FIRMS MORE THAN SMES IN VIETNAM?

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Abstract:

Digital transformation is widely regarded as a pathway to greener logistics, yet its benefits may be unevenly distributed across firms. This study examines whether Industry 4.0 adoption creates a digital divide in green logistics between small and medium-sized enterprises (SMEs) and large firms, and identifies where this divide emerges within the causal process. Integrating digital divide theory with the resource-based view and dynamic capabilities perspective, the study distinguishes among access, capability, and outcome divides. The proposed relationships are tested using a stratified sample of 205 Vietnamese firms, complemented by 15 expert interviews. The findings show that large firms adopt Industry 4.0 technologies more extensively than SMEs and convert such adoption into green logistics capabilities more effectively ($\beta = 0.68$ vs. 0.42 ; interaction $p = 0.002$), resulting in significantly stronger indirect effects on firm performance. However, the effect of green logistics capability on performance does not differ significantly by firm size. These results indicate that the digital divide is concentrated primarily in capability formation rather than in the subsequent exploitation of green logistics capabilities.

Keywords: digital divide, SMEs, green logistics management, Industry 4.0, dynamic capabilities

JEL Classification: L91, O33, Q56, M11.

Khoảng cách số trong quá trình chuyển đổi logistics xanh: Vì sao Cách mạng Công nghiệp 4.0 mang lại lợi ích nhiều hơn cho các doanh nghiệp lớn so với doanh nghiệp vừa và nhỏ tại Việt Nam?

Tóm tắt:

Chuyển đổi số được xem là con đường hướng tới logistics xanh, song lợi ích của nó có thể phân bổ không đồng đều giữa các doanh nghiệp. Nghiên cứu này đặt câu hỏi liệu việc ứng dụng công nghệ Công nghiệp 4.0 có tạo ra khoảng cách số trong logistics xanh giữa doanh nghiệp nhỏ và vừa (DNNVV) và doanh nghiệp lớn hay không, và khoảng cách đó phát sinh ở khâu nào trong chuỗi nhân quả. Kết hợp lý thuyết khoảng cách số với quan điểm dựa trên nguồn lực và năng lực động, nghiên cứu phân biệt ba cấp độ khoảng cách (tiếp cận, năng lực và kết quả), kiểm định trên mẫu phân tầng gồm 205 doanh nghiệp Việt kết hợp với 15 phỏng vấn chuyên gia. Kết quả cho thấy doanh nghiệp lớn ứng dụng Công nghiệp 4.0 nhiều hơn DNNVV (khoảng cách tiếp cận) và, quan trọng hơn, chuyển hóa việc ứng dụng thành năng lực logistics xanh hiệu quả hơn hẳn ($\beta = 0,68$ so với $0,42$; tương tác $p = 0,002$), dẫn tới tác động gián tiếp lên kết quả hoạt động lớn hơn đáng kể (khoảng cách kết quả). Tuy nhiên, tác động của năng lực logistics xanh lên kết quả hoạt động không phụ thuộc quy mô, cho thấy khoảng cách nằm ở khâu hình thành năng lực chứ không phải khâu khai thác.

Từ khóa: khoảng cách số, doanh nghiệp nhỏ và vừa, logistics xanh, Công nghiệp 4.0, năng lực động

1. Introduction

Two transformations are converging on logistics. The first is digital: Industry 4.0 technologies - big data analytics, cloud computing, the Internet of Things, blockchain, and artificial intelligence - are reshaping how goods are planned, moved, stored, and tracked. The second is environmental: regulatory and market pressure, crystallized in instruments such as the EU Carbon Border Adjustment Mechanism, is forcing firms to decarbonize operations in which logistics figures prominently. A growing literature argues that the first transformation can accelerate the second (Kayikci, 2018; Wang et al., 2023). What this optimistic narrative overlooks is distribution: even where digitalization greens logistics on average, its benefits may accrue unevenly, and the firms least able to capture them may be those a green transition can least afford to leave behind.

That concern is sharp in economies where small and medium-sized enterprises (SMEs) predominate - approximately 97% of all firms in Vietnam - yet operate under capital, skills, and infrastructure constraints that large firms do not face. The information-systems literature has long held that the digital divide is not merely a gap in access to technology but, more consequentially, a gap in the capability to use it productively and to benefit from it (Attewell, 2001; van Dijk, 2020). If converting digital investment into green logistics capability depends on complementary resources that SMEs lack, the digital-green transition could widen existing inequalities between firms rather than narrow them.

Prior research on Industry 4.0 and green logistics has largely treated firms as homogeneous adopters, with firm size appearing as a statistical control rather than an object of analysis (Choi & Zhang, 2011; Trivellas et al., 2020). This leaves a substantive research gap: the literature can say that digitalization helps green logistics on average, but not for whom, nor at which stage of the causal chain any inequality emerges. Vietnam offers a particularly informative setting for closing this gap, since its National Green Growth Strategy (2021-2030) and its SME support framework under Decree No. 80/2021/ND-CP pursue digitalization and decarbonization simultaneously in an economy overwhelmingly composed of SMEs.

This study therefore makes firm size the center of the analysis rather than a control. Drawing on digital divide theory and on the resource-based and dynamic-capabilities perspectives, it asks whether SMEs and large firms differ in adoption (an access divide), in the conversion of adoption into green logistics capability (a capability divide), and in the performance benefits ultimately realized (an outcome divide), and whether the divide originates in the formation of capability, in its exploitation, or in both. The contribution is threefold: theoretically, it transposes the multi-tier digital divide framework from individuals to firms in a sustainability context; empirically, it provides subgroup and moderated-mediation evidence from a stratified Vietnamese sample; and practically, it identifies the precise stage at which policy intervention would be most efficient.

2. Literature review and research methodology

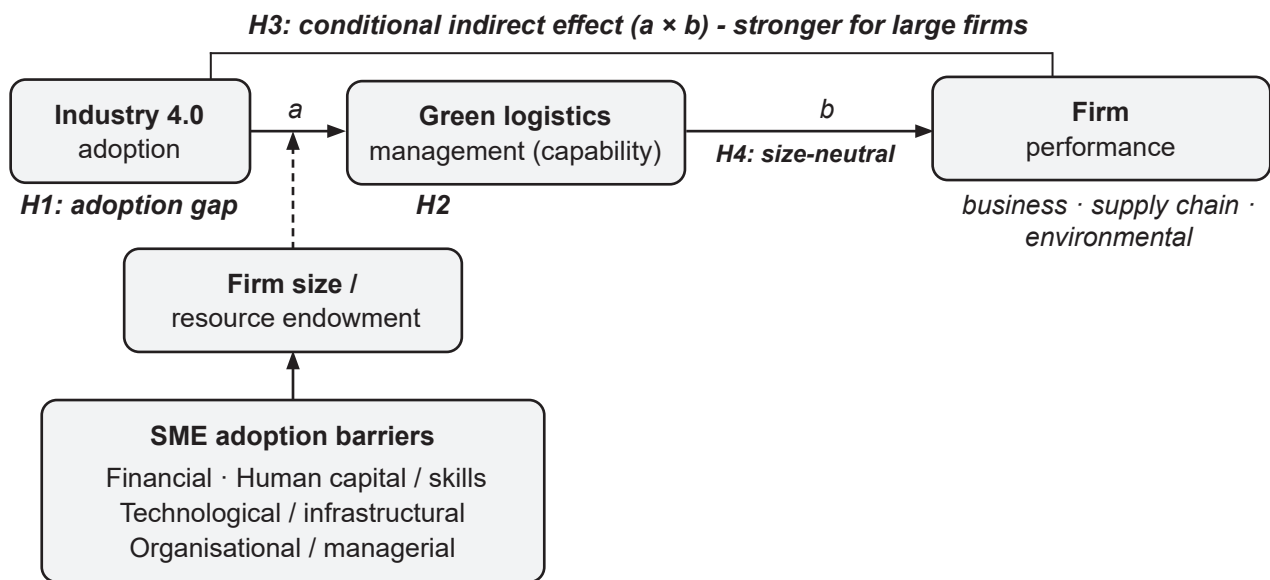
2.1. Theoretical background and hypotheses

Digital divide theory distinguishes successive tiers of inequality. The first-order divide concerns access to technology; the second-order divide concerns the skills and capability to use it productively; and the third-order divide concerns the tangible benefits that accrue from that use (Attewell, 2001; van Dijk, 2020). Although developed to explain inequality among individuals, this logic transfers naturally to firms, where the resource-based view holds that technology alone is not a source of advantage - its value depends on complementary organizational resources that are unevenly distributed (Bharadwaj, 2000) - and where the dynamic-capabilities view holds that converting technology into operational capability requires sensing, seizing, and reconfiguration capacity that scales with organizational slack (Teece et al., 1997).

Green logistics management (GLM) is treated here as precisely such a capability: an organizational competence in emissions tracking, network optimization, green warehousing, and sustainable packaging that firms build rather than buy. The framework (Figure 1) accordingly recasts the digitalization-green

logistics-performance chain as a distributional process moderated by firm size. Aggregate Industry 4.0 adoption is modelled as an antecedent of GLM (the a-path), which in turn drives firm performance (the b-path); firm size, as a proxy for resource endowment, moderates the chain, and SME resource barriers constitute the underlying mechanism.

Figure 1. The three-tier digital divide in green logistics transformation



Source: Authors' proposal

H1 (access divide). Because Industry 4.0 technologies entail fixed costs that weigh more heavily on resource-constrained firms, SMEs exhibit lower adoption than large firms.

H2 (capability divide). Even at equal adoption, converting technology into green logistics capability requires complementary resources and reconfiguration that favour larger firms; the adoption-capability relationship is therefore stronger for large firms (firm size positively moderates the a-path).

H3 (outcome divide). The capability divide propagates into unequal benefits: the indirect effect of adoption on performance through green logistics management is larger for large firms than for SMEs.

H4 (exploitation parity). Once green logistics capability is built, exploiting it depends less on scale, so the effect of green logistics management on performance (the b-path) is size-neutral. Support for H4 would localize the divide in capability formation rather than exploitation.

2.2. Research methodology

Research design. A sequential explanatory mixed-methods design was adopted, in which a quantitative survey establishes the pattern of divides and a subsequent qualitative phase explains the mechanism behind them. Because firm size is the focal variable rather than a control, the sample was stratified ex ante by the national size classification set out in Decree No. 80/2021/ND-CP (Government of Vietnam, 2021).

Sampling and data collection. A structured questionnaire was administered online to firms operating in the southern region of Vietnam between December 2023 and March 2024, yielding 205 usable responses (an 82% response rate): 123 SMEs (60%) and 82 large firms (40%). One senior logistics, supply chain, or procurement manager responded per firm, ensuring that respondents held the authority and knowledge required to report on both technology adoption and logistics practice. Respondents were highly experienced, with 80.5% reporting more than ten years of professional experience, and highly educated, with 96.3% holding a university degree or above. Fifteen semi-structured interviews with managers drawn from both size strata were subsequently conducted and thematically analysed in NVivo to identify the barriers underlying the quantitative pattern.

Measurement. All constructs were measured on five-point Likert scales adapted from validated instruments: Industry 4.0 technology adoption from Wang et al. (2023), green logistics management from Choi and Zhang (2011), and the three firm-performance dimensions from Trivellas et al. (2020). All core constructs met the .70 reliability threshold (Cronbach's $\alpha = .767-.817$). Exploratory factor analysis supported the factor structure (KMO = .715; Bartlett's $\chi^2 = 1,539.45$, $p < .001$), and confirmatory factor analysis in AMOS indicated acceptable fit (CFI = .95, TLI = .94, RMSEA = .06, SRMR = .05), with all factor loadings exceeding .50 and average variance extracted above .50 for each construct. Measurement invariance across the two size strata was adequate, permitting subgroup comparison.

Analytical strategy. Analyses proceeded in three steps corresponding to the three tiers of the divide. First, independent-samples t-tests compared SMEs and large firms on adoption and on all outcome variables (access divide). Second, the a-path was estimated separately within each size subgroup and a formal firm-size interaction term was tested (capability divide). Third, a moderated-mediation model was estimated using the PROCESS macro with 5,000 bootstrap resamples (Hayes, 2018), yielding conditional indirect effects, an index of moderated mediation, and a separate interaction test on the b-path (outcome divide and exploitation parity). Firm age and industry type were entered as controls throughout.

3. Results and discussion

3.1. The access divide

The first tier of the divide was clearly evident. Large firms reported significantly higher Industry 4.0 adoption than SMEs ($M = 3.81$ vs 3.21 ; $t(203) = 5.62$, $p < .001$, $d = 0.82$), a large effect by conventional standards. Parallel and statistically significant gaps appeared in green logistics management and in all three performance dimensions (Table 1), all favoring large firms. H1 is therefore supported. Notably, however, the effect sizes decline monotonically as one move from adoption ($d = 0.82$) through capability ($d = 0.69$) to the performance outcomes ($d = 0.56-0.58$), which already hints that the gap is generated upstream rather than accumulating uniformly along the chain.

Table 1. Firm-size comparisons (independent-samples t-tests; $N = 205$)

Variable	SME M (SD)	Large M (SD)	t	p	d
Industry 4.0 adoption	3.21 (0.74)	3.81 (0.71)	5.62	< .001	0.82
Green logistics management	3.45 (0.63)	3.88 (0.60)	4.78	< .001	0.69
Business performance	3.42 (0.70)	3.82 (0.68)	3.98	< .001	0.58
Supply chain performance	3.55 (0.67)	3.93 (0.64)	3.95	< .001	0.57
Environmental performance	3.40 (0.69)	3.78 (0.66)	3.85	< .001	0.56

Source: Authors' survey data ($N = 205$); d = Cohen's d , two-tailed tests

3.2. The capability divide

The second tier is the study's central finding. Across the pooled sample, Industry 4.0 adoption significantly predicted green logistics management ($\beta = .58$, $p < .001$, $R^2 = .38$), replicating the aggregate relationship reported in the existing literature. That pooled coefficient, however, conceals a pronounced asymmetry. Estimated separately by subgroup, adoption predicted green logistics management far more strongly among large firms ($\beta = .68$, $p < .001$) than among SMEs ($\beta = .42$, $p = .008$), and the firm-size interaction on the a-path was significant ($\beta = .25$, $p = .002$). Substantively, an equivalent increment of digital adoption yields roughly 60% more green logistics capability in a large firm than in an SME. H2 is supported.

This result is consequential precisely because it is invisible in aggregate analysis. A study reporting only the pooled $\beta = .58$ would conclude that digitalization reliably supports green logistics and would

recommend broad adoption incentives. The subgroup decomposition shows instead that the same technological investment buys markedly different amounts of capability depending on who makes it.

3.3. The outcome divides and exploitation parity

The capability gap propagated into unequal benefits. Conditional indirect effects of adoption on performance through green logistics management were significantly larger for large firms across all three outcomes, and the index of moderated mediation was significant in each case (Table 2), supporting H3. For supply chain performance, for instance, the indirect effect was .38 (95% CI [.28, .49]) among large firms but only .24 (95% CI [.15, .32]) among SMEs.

Table 2. Conditional indirect effects and index of moderated mediation

Outcome variable	SME indirect effect	Large-firm indirect effect	Index of moderated mediation [95% CI]
Business performance	.21 [.13, .30]	.33 [.24, .43]	.12 [.03, .22]
Supply chain performance	.24 [.15, .32]	.38 [.28, .49]	.15 [.05, .26]
Environmental performance	.25 [.16, .34]	.39 [.29, .50]	.14 [.04, .25]

Source: PROCESS moderated-mediation estimates, 5,000 bootstrap resamples

Critically, firm size did not moderate the b-path. The effect of green logistics management on performance did not differ significantly between SMEs and large firms (interaction $\beta = .06$, $p = .44$), supporting H4. Once green logistics capability exists, in other words, it converts into performance at essentially the same rate regardless of firm size. The divide therefore originates specifically in capability formation and not in capability exploitation - an SME that succeeds in building green logistics capability captures the returns as fully as a large firm does.

3.4. Qualitative explanation of the formation gap

Thematic analysis of the fifteen interviews explained the formation gap through four categories of barrier concentrated among SMEs, reported here in order of prominence. Financial barriers were mentioned most frequently, centering on the capital cost of platforms, sensors, and especially analytics and artificial-intelligence capability, together with the difficulty of justifying payback periods that exceed SME planning horizons. Human-capital barriers followed: data analytics and sustainability expertise are scarce and expensive, and SMEs compete for the same talent as far better-resourced employers. Technological and infrastructural barriers concerned legacy systems, fragmented data, and the complexity of integrating new tools into existing operations. Organizational and managerial barriers concerned limited managerial bandwidth and the absence of any dedicated sustainability or digital function, so that transformation competes directly with day-to-day operations for the attention of the same few managers.

Two features of the interview evidence deserve emphasis. First, every one of these barriers bears on the formation of capability rather than on its use, which converges with the quantitative finding that the moderation is confined to the a-path. Second, several SME informants stressed that the value of green logistics itself was not in doubt where they had managed to implement it; their difficulty lay in reaching implementation, not in profiting from it. This is precisely what a size-neutral b-path would predict, and the convergence of the two methods on the same conclusion strengthens confidence in it.

3.5. Discussion

These results recast digital-green transformation as a distributional process and locate where inequality arises within it. Consistent with digital divide theory (Attewell, 2001; van Dijk, 2020), all three tiers were identified - an access divide in adoption, a capability divide in conversion, and an outcome divide in benefits - with the capability divide proving decisive. This pattern is consistent with resource-based and dynamic-capabilities reasoning that the productive use of technology depends on complementary

resources and reconfiguration capacity that scale with firm size (Bharadwaj, 2000; Teece et al., 1997). The propagation of the gap into performance is consistent with a Matthew effect (Merton, 1968): absent intervention, the digital-green transition may widen rather than narrow the distance between large firms and SMEs.

The findings both extend and qualify the existing literature. They extend Wang et al. (2023) and Kayikci (2018) by confirming that Industry 4.0 adoption supports green logistics, and Trivellas et al. (2020) by confirming that green logistics management improves performance. They qualify both, however, by showing that these aggregate relationships mask systematic heterogeneity: treating firm size as a control, as most prior studies have done, produces an average effect that describes no actual firm well and supports policy advice that may be counterproductive for the majority of firms. The result also complements the barrier taxonomies of Chhabra and Singh (2022) and the SME digitalization literature (Eller et al., 2020; OECD, 2021) by showing not merely that SMEs face barriers, but that those barriers bind at one identifiable stage of the causal chain.

4. Conclusion

This study asked whether Industry 4.0 produces a digital divide in green logistics transformation, and where in the causal chain that divide arises. Using a stratified sample of 205 Vietnamese firms and fifteen expert interviews, it found evidence of all three tiers of the divide, and established that the decisive inequality lies in the conversion of digital adoption into green logistics capability ($\beta = .68$ for large firms versus $.42$ for SMEs) rather than in the subsequent conversion of that capability into performance, which proved size-neutral.

The contrast between the moderated a-path and the size-neutral b-path carries the study's principal policy implication: the divide lies in capability formation, not exploitation, and is therefore addressable at a specific and identifiable stage. Adoption subsidies that place technology in SMEs' hands without simultaneously building the complementary capability risk widening the second-order divide, because they raise adoption without raising the rate at which adoption converts into capability. More effective instruments target formation directly: shared digital-green platforms and industry-association service models that socialize the fixed costs identified in the interviews; capability-building programs in data analytics and sustainable logistics aimed at SME managers and technical staff; and financing structured for the complementary organizational investments that capability formation requires rather than for equipment alone. Because the returns to capability are size-neutral, such support is efficient: it addresses the stage where the gap actually is and allows the size-neutral performance path to carry the benefits through.

Three limitations qualify these conclusions and suggest directions for further work. The cross-sectional design permits inference about association and mediation structure but not about causal sequence over time, and longitudinal or panel data would establish whether the capability gap widens, persists, or closes as adoption matures. The sample is confined to southern Vietnam, so generalization to other regions or to other emerging economies requires replication. Finally, Industry 4.0 adoption was modelled at the aggregate level; given that constituent technologies plausibly differ in the complementary resources they demand, disaggregating the divide by specific technology is a natural extension. For an economy in which SMEs constitute the overwhelming majority of firms, a green-growth strategy relying on digital transformation must actively support SME capability formation, or it will widen the very gap it seeks to close ■

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