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Modeling Tomorrow: Innovation for Sustainable Development Innovation Systems, Technological Capabilities, and Sustainability Transitions in Latin America and the Caribbean



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Modeling Tomorrow: Innovation for Sustainable Development

Innovation Systems, Technological Capabilities, and Sustainability Transitions in Latin America and the Caribbean

CHAPTER II.

II. Building Innovation Capabilities in Small and Open Economies

Compliance as Catalyst: Digital-Sustainable Capability Building in a Border-Region Economy

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1. Introduction

Digitalization and sustainability increasingly operate as overlapping transformation pressures. Digital Transformation (DT) has become a strategic organizational process that affects operations, value creation, data use, and competitive positioning (Kraus et al., 2021, 2022). Sustainable Transformation (ST), in turn, requires firms to integrate environmental and social objectives into strategy, governance, and business models rather than treating sustainability as an isolated compliance activity (Geissdoerfer et al., 2017; Broccardo et al., 2023). Their simultaneous pursuit is increasingly conceptualized in the literature as a twin transition or digital-sustainable transformation, reflecting the potential complementarities between digital and sustainable capabilities (Guandalini, 2022).

The notion of dual transformation was originally articulated by Anthony, Gilbert, and Johnson (2017) as an organizational response to disruptive change. Their framework distinguishes between Transformation A, which repositions and strengthens the existing core business, and Transformation B, which creates a separate new growth engine, connected through a capabilities link that enables firms to leverage existing organizational assets while developing new trajectories. Rather than treating transformation as a single process, this perspective emphasizes the organizational challenge of managing two distinct but interconnected transformation pathways simultaneously.

In border-region economies, however, transformation takes place under distinctive institutional and market conditions. Firms may be closely connected to international production networks while simultaneously facing uneven access to innovation infrastructure, knowledge, finance, and local support. Tijuana, Mexico, provides a useful setting because firms operate next to the United States market and combine export-oriented manufacturing, services, commerce, and firms serving primarily local and regional markets.

The 148-firm database has already informed two related studies from the same research team. Encinas-Grijalva et al., (2024) designed and validated the self-diagnosis instrument used throughout this research stream and applied it to assess firms' overall readiness for dual transformation. That study found intermediate readiness levels for both DT and ST and identified strategy, organizational culture, organizational structure, and technical capabilities as the dimensions that most strongly explained readiness, with strong positive correlations observed across dimensions within each transformation type. Rosales-Soto *et al*. (2026) previously used this dataset to develop and apply the Dual Transformation Maturity Index (DTMI), mapping firms according to digital and sustainable maturity and identifying four transformation pathways. On average, that study found that sustainability transformation maturity exceeded digital

transformation maturity across the sample, pointing to uneven capability development across the two dimensions. That analysis revealed a counterintuitive pattern: export-oriented and formally certified firms did not systematically occupy the most advanced dual-transformation positions. The present article does not reproduce that mapping as its principal contribution. Instead, it builds on the earlier finding and asks a different question: how is combined exposure to export markets and formal quality certification associated with digital and sustainable capability building?

This study proposes the concept of compliance-driven capability building to describe a pattern in which firms' exposure to external requirements: through export markets and formal certification, is associated with stronger, rather than weaker, organizational capabilities for digital and sustainable transformation. The research question is: How is exposure to export markets and formal quality certification associated with DT and ST maturity among firms in a border-region economy, and do the observed patterns support a capability-building interpretation of compliance exposure? The objective is interpretive rather than causal: the cross-sectional evidence cannot establish that compliance causes higher transformation maturity.

2. Literature Review

2.1 Dual transformation as capability building

Digital Transformation (DT) is more than technology acquisition. It involves strategic alignment, organizational culture, data-driven decision making, employee learning, governance, and integration of information systems. Similarly, Sustainable Transformation requires firms to embed economic, environmental, and social considerations into strategy, processes, organizational responsibilities, knowledge management, and decision making. Research increasingly emphasizes that digital technologies can support sustainability through resource efficiency, traceability, information processing, and innovation (Ji et al., 2023; Lu et al., 2023; Song et al., 2024). The relevant question is therefore not simply whether firms adopt digital or sustainability practices, but whether they develop the organizational capabilities that allow both transformations to become embedded and mutually reinforcing.

Dynamic-capability research provides one organizational explanation: firms must sense technological and environmental changes, seize opportunities, and reconfigure resources as conditions evolve. From an innovation-and-development perspective, this points toward capability accumulation rather than adoption alone. Formal systems may provide routines and discipline, but transformation also requires learning, coordination, experimentation, and the capacity to adapt externally acquired practices to the firm's own strategic context.

2.2 External integration and the compliance-capability gap

Participation in international markets and formal certification can create important learning opportunities. Exporting exposes firms to demanding customers, technologies, and competitive benchmarks, while quality standards can institutionalize processes and improve reliability. Theoretical accounts differ, however, on whether this exposure translates into deeper organizational capability or remains confined to meeting external specifications, audit requirements, and delivery targets without broader transformation.

One strand of institutional theory would predict the opposite pattern. Meyer and Rowan's (1977) foundational account of decoupling holds that organizations often adopt formal structures to secure legitimacy while day-to-day activity remains loosely coupled from those structures, and empirical work on certifiable management standards shows that firms sometimes calibrate compliance symbolically, meeting external requirements without deeper substantive change (Christmann & Taylor, 2006; Boiral, 2007), particularly where compliance-focused routines compete with the organizational resources needed for capability development (Cao & Jayasinghe, 2024). A contrasting stream of research, however, documents substantive rather than symbolic effects of external market and certification exposure. Firm-level evidence on learning by exporting shows that exposure to foreign buyers and markets can transfer knowledge that raises innovation outcomes (Salomon & Shaver, 2005) and signaling-based accounts of certification find that certified firms grow faster after certification through channels other than immediate operational improvement, consistent with certification functioning as a credible signal that firms invest in to build and demonstrate capability (Terlaak & King, 2006).

Recent work on dual transformation similarly distinguishes immediate efficiency gains from longer-term capability development, showing that the two mechanisms can coexist but need not advance at the same rate. Alabduljabbar (2026) examines how Saudi Arabia´s Vision 2030 reforms: digitalization, localization and regulatory change, shape supply chain outcomes through two parallel pathways: direct, short-term efficiency and service-performance gains, and indirect, longer-term capability development mediated by organizational readiness as a dynamic capability. Using a mixed-methods design combining PLS-SEM survey data from 247 professionals with 20 interviews across 14 sectors, the study finds that the efficiency-oriented pathway accounts for the majority of observed effects (54%-65%), while capability development explains a smaller but substantial share (35%-46%), with logistics sectors favoring efficiency gains and manufacturing sectors favoring capability building. This evidence reinforces the view that dual transformation operates through coexisting rather than competing mechanisms, and its relative balance is conditioned by sectoral and institutional context, a pattern consistent with the heterogeneity observed among firms in Tijuana’s business ecosystem.

This study therefore uses compliance-capability gap as an interpretive concept rather than a predetermined causal mechanism. A persistent gap could become a compliance trap when externally oriented routines repeatedly satisfy immediate requirements without being converted into endogenous learning and transformation capabilities.

3. Methodology

This study conducts a secondary analysis of the 148-firm dataset previously used to map dual-transformation maturity in Tijuana (Rosales-Soto et al., 2026; Encinas-Grijalva, et al., 2024). Data were collected between 2022 and mid-2023 through a structured self-diagnosis questionnaire adapted from Encinas-Grijalva et al., (2024). Respondents occupied managerial or decision-making positions and represented firms of different sizes, sectors, export orientations, additional locations outside Tijuana, and certification statuses.

The instrument contains 24 five-point Likert items. Consistent with the original instrument (Encinas-Grijalva et al., 2024), items are scored so that lower values indicate stronger self-assessed alignment with the ideal transformation state described by each item. Items 1–12 measure Digital Transformation and items 13–24 measure Sustainable Transformation.

Firm-level DT and ST scores were calculated as the mean of the corresponding 12 items, and reverse-scored into a Maturity Index (6 minus the raw mean) so that higher values indicate higher maturity; this index is used throughout the results reported below. Internal consistency is high (DT Cronbach's $\alpha = 0.945$; ST $\alpha = 0.971$), consistent with Encinas-Grijalva et al. (2024).

To provide an analysis not reported in the previous DTMI paper, export status and formal quality certification were combined into an ordinal compliance-exposure indicator: 0 = neither exporter nor formally certified; 1 = exporter or formally certified; and 2 = both exporter and formally certified. This measure does not imply that exporting or certification is intrinsically negative; it captures increasing simultaneous exposure to two formal external-demand conditions. Mean DT and ST maturity were compared across the three groups using one-way analysis of variance (ANOVA). Effect sizes were estimated using eta squared (η^2), and Tukey HSD post-hoc tests were used to identify pairwise differences between exposure groups. A combined dual-transformation score, calculated as the mean of DT and ST, was used for a complementary rank-order association test. Because the study is cross-sectional and based on self-reported perceptions, results are interpreted as associations rather than causal effects.

4. Analysis of Results

4.1 Sample characteristics

The final sample comprised 148 firms operating in Tijuana, Mexico. Table 1 summarizes the sample's sectoral composition, firm-size distribution, export status, and certification status. Services firms account for the majority of the sample (57.4%), followed by manufacturing, wholesale trade, and retail trade. Most firms are micro or small, with just over a quarter reporting 51 or more employees. Non-exporters (71.6%) and non-certified firms (61.5%) form most of the sample, consistent with the compliance-exposure groupings examined in Section 4.2.

Table 1. Sample characteristics (N = 148)

Characteristic	Category	n	%
Sector	Services	85	57.4
	Manufacturing	23	15.5
	Wholesale trade	22	14.9
	Retail trade	18	12.2
Firm size (employees)	0–20 (micro)	49	33.1
	21–50	59	39.9
	51 or more	40	27.0
Export status	Exporter	42	28.4
	Non-exporter	106	71.6
Quality certification	Certified	57	38.5
	Not certified	91	61.5

Source: Authors' analysis based on the 148 firm survey database.

4.2 Compliance exposure and transformation maturity

The compliance-exposure grouping reveals a clear monotonic pattern in transformation maturity. Seventy-four firms are neither exporters nor formally certified (Low exposure), 49 meet one of the two conditions (Moderate exposure), and 25 are simultaneously exporters and certified (High exposure). As detailed in Table 2, DT maturity rises from 3.30 in the low-exposure group to 3.92

under moderate exposure and 4.08 under high exposure. ST follows the same pattern, increasing from 3.05 to 3.63 and 3.92, respectively, while the combined maturity index rises from 3.18 to 3.78 and 4.00.

To evaluate whether external-demand pressure differentiates organizational maturity, a three-step analytical strategy was implemented. First, a one-way analysis of variance (ANOVA) was conducted to determine whether mean maturity levels across the three exposure groups (Low, Moderate, and High) reflect statistically significant omnibus differences rather than random sampling variation, estimating effect sizes (η^2 and ω^2) to quantify the proportion of total variance explained by compliance pressure. Second, because the omnibus-test only detects overall group divergence, Tukey's Honestly Significant Difference (HSD) post-hoc comparisons were applied to prevent Type I error inflation and pinpoint which specific group transitions drive the differences. Finally, given that compliance exposure represents an ordered categorical construct, a non-parametric Spearman rank correlation (ρ) was conducted as a complementary robustness test to evaluate the monotonic strength and direction of this relationship without assuming strict interval scaling or normality.

Table 2. Dual-transformation maturity index by external compliance exposure

Exposure	Definition	n	DT Index (SD)	ST Index (SD)	Combined Index
Low	Neither	74	3.330 (0.98)	3.05 (1.12)	3.18 (0.95)
Moderate	Exporter or certified	49	3.92 (0.98)	3.63 (0.91)	3.78 (0.87)
High	Exporter + certified	25	4.08 (1.00)	3.92 (1.08)	4.00 (0.95)
		148			

Source: Authors' analysis based on the 148 firm survey databases.

Note. Maturity Index = 6 minus the mean raw item score (1–5 scale); higher values indicate higher digital (DT) or sustainable (ST) transformation maturity.

As shown in Table 3, one-way analysis of variance confirms that these differences across exposure groups are statistically significant for DT ($F(2,145) = 9.04$, $p < .001$), ST ($F(2, 145) = 8.32$, $p < .001$), and the combined index ($F(2, 145) = 10.43$, $p < .001$). Effect sizes were $\eta^2 = .111$ ($\omega^2 = .098$) for DT, $\eta^2 = .103$ ($\omega^2 = .090$) for ST, and $\eta^2 = .126$ ($\omega^2 = .113$) for the combined index, indicating that compliance exposure accounts for approximately 10% to 13% of the observed variance in organizational maturity. Figure 1 visually depicts this monotonic progression across all three dimensions.

Table 3. ANOVA and Tukey HSD post-hoc comparisons across compliance-exposure groups

Dependent Variable	Model Parameter / Comparison	Mean Diff.	SE	t	p	Effect Size (n^2/d)
DT Index	ANOVA Omnibus			F=9.04	<.001	n^2=.111
	Low vs. Moderate	-0.621	0.180	-3.44	.002	d=-0.63
	Low vs. High	-0.783	0.226	-3.46	.002	d=-0.80
	Moderate vs. High	-0.162	0.241	-0.67	.780	d=-0.17
ST Index	ANOVA Omnibus			F=8.32	<.001	n^2=.103
	Low vs. Moderate	-0.579	0.193	-3.00	.009	d=-0.55

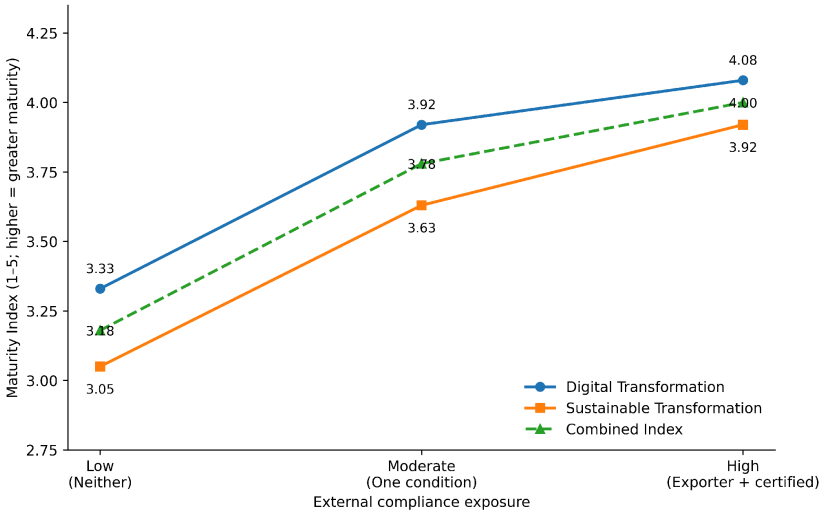
Dependent Variable	Model Parameter / Comparison	Mean Diff.	SE	t	p	Effect Size (n^2/d)
Combined Index	Low vs. High	-0.866	0.242	-3.57	.001	d=-0.83
	Moderate vs. High	-0.287	0.257	-1.12	.506	d=-0.27
	ANOVA Omnibus			F=10.43	<.001	n^2=.126
	Low vs. Moderate	-0.600	0.170	-3.54	.002	d=-0.65
	Low vs. High	-0.824	0.213	-3.87	<.001	d=-0.89
	Moderate vs. High	-0.224	0.227	-0.99	.584	d=-0.24

Source: Authors' analysis based on *Jamovi* output (emmeans and car packages). Degrees of freedom: df1=2, df_2 =145. p-values for pairwise comparisons are adjusted using Tukey's HSD test.

Tukey HSD post-hoc comparisons show that the low-exposure group has significantly lower maturity than the moderate-exposure group for DT (p=.002, d=−0.63), ST (p=.009, d=−0.55), and the combined index (p = .002, d = −0.65). Differences between the low- and high-exposure groups are also significant for DT (p = .002, d = −0.80), ST (p = .001, d = −0.83), and the combined index (p < .001, d = −0.89). In contrast, differences between the moderate- and high-exposure groups are not statistically significant for DT (p = .780, d = −0.17), ST (p = .506, d = −0.27), or the combined index (p = .584, d = −0.24).

Thus, although mean maturity increases monotonically across the three exposure levels, the post-hoc results reveal a clear threshold pattern: exposure to at least one external-demand condition (exporting or certification) substantively and significantly distinguishes firms from those facing neither requirement, whereas simultaneous exposure to both conditions yields incremental but not statistically distinct gains. As a complementary ordinal test, compliance exposure exhibits a positive and statistically significant association with the combined maturity index (Spearman ρ=0.361, p<.001, df=146). These results do not imply direct causality; rather, they demonstrate that, within this industrial sample, exposure to external regulatory and market pressures is systematically paired with higher self-assessed transformation capabilities.

Figure 1. Digital and sustainable maturity index by compliance exposure.



Source: Authors' analysis.

4.3 Compliance-driven capability building

The pattern is important because firms exposed to at least one external-demand condition report significantly higher self-assessed transformation maturity than firms exposed to neither condition. While the high-exposure group reports the highest mean maturity, its scores are not statistically distinguishable from those of the moderate-exposure group. This threshold pattern is consistent with a capability-building account of external integration: exposure to buyer requirements, international competition, formal standards, and third-party audits may be associated with stronger digital and sustainable transformation maturity.

Exporting firms operating within international production systems are exposed to demanding customers, foreign competitors, and technology transfer that can accelerate organizational learning, consistent with learning-by-exporting accounts of firm capability development (Salomon & Shaver, 2005). Certification can similarly function as more than a compliance cost: because certification credibly signals underlying organizational quality to customers and partners, firms may be motivated to invest in the substantive capabilities that certification is meant to signal, generating real, not merely symbolic, improvement (Terlaak & King, 2006).

Compliance, in this reading, is not a substitute for capability building but a potential channel through which organizational learning and upgrading may occur. For Tijuana's innovation ecosystem, this suggests that programs connecting certification and export support with managerial learning, digital integration, supplier development, university-industry collaboration, and sustainability innovation may reinforce a capability-building dynamic that export and certification exposure already appear to support.

The significant differences between firms with no exposure and those with at least one external-demand condition also point to a potential capability-exposure gap: firms outside export markets and formal certification systems may have less access to the learning pressures, benchmarks, and organizational routines associated with these environments. This does not imply that policy should simply increase regulatory requirements. Rather, export-readiness and certification instruments can be designed as learning infrastructures that broaden access to capability-building opportunities, particularly for firms currently outside these external-demand environments.

5. Concluding Remarks

This article extends the earlier DTMI mapping of Tijuana firms by examining a new question: whether exposure to export markets and formal quality certification corresponds with stronger digital and sustainable transformation maturity. The evidence shows a clear monotonic pattern in the predicted direction. Firms with neither condition report the lowest mean DT and ST maturity; firms with one condition occupy an intermediate position; and firms that are both exporters and certified report the highest mean maturity. However, Tukey HSD comparisons show that the statistically significant differences occur between firms with no external compliance exposure and those exposed to at least one condition, whereas the additional difference between moderate and high exposure is not statistically significant.

This result is consistent with compliance-driven capability building, but it does not prove that exporting or certification causes stronger transformation. External requirements associated with

export markets and formal certification may function as channels through which firms are exposed to demanding buyers, competitive benchmarks, and structured process requirements that, over time, may contribute to broader digital and sustainable transformation capability, consistent with learning-by-exporting and certification-signaling perspectives.

The implication for innovation and development policy is that participation in global markets and formal standards should be treated as a plausible capability-building lever, not merely a compliance cost. The results also suggest a potential capability-exposure gap affecting firms that neither export nor participate in formal certification systems. Programs that pair export and certification support with digital skills, data use, organizational learning, sustainability strategy, supplier development, and collaborative innovation may therefore help broaden access to the learning mechanisms associated with external-demand exposure. Rather than increasing compliance for its own sake, policy can design these instruments as learning infrastructures that support more inclusive digital and sustainable capability building. This is particularly relevant for regions such as Tijuana, where proximity to global markets creates opportunities for technological and organizational upgrading that may not be evenly distributed across the business ecosystem.

The study has three limitations. First, its cross-sectional design prevents causal inference; the direction of the association between compliance exposure and maturity cannot be established from these data alone. Second, the measures are based on managerial self-assessment. Third, the compliance-exposure indicator is intentionally parsimonious and captures only export participation and formal quality certification. Future research could test the compliance-driven capability-building proposition longitudinally, distinguish types and intensity of certification, incorporate export dependence and buyer relationships, and examine whether local innovation-system linkages further strengthen the capability-building dynamic observed here.

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