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Perceived organisational barriers to coordinating digital and green transformations in Spanish manufacturing firms

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Abstract

The twin transition assumes that digital transformation and environmental sustainability can generate mutually reinforcing benefits, yet firms often face organisational difficulties in coordinating them. This study examines the factors associated with digital-sustainability coordination barriers and their relationship with sustainability strategy in Spanish manufacturing firms. Using data from the 2022 Spanish Survey of Business Strategies (ESEE), we estimate probit and ordered response models with robustness checks. Results show that skills shortages and insufficient integration of sustainability into business models are positively associated with coordination barriers, whereas business-model incompatibility is not statistically significant. Coordination barriers are not significantly associated with sustainability strategies. These findings highlight the importance of workforce skills and business-model integration in understanding the organisational challenges of the twin transition.

1. Introduction

Manufacturing firms face two major transformations: advanced digitalisation and the green transition (Miró-Pérez et al., 2026). The “Twin Transition” emphasises their potential complementarities, whereby Industry 4.0 technologies can support sustainability, circular economy practices, and eco-innovation (Hoosain et al., 2023; Siakas et al., 2023). Technologies such as Big Data, the Industrial Internet of Things (IIoT), and Artificial Intelligence (AI) can facilitate resource monitoring, energy efficiency, and product life-cycle management (Sroufe, 2017; Anshari & Ordóñez de Pablos, 2025). However, these complementarities are not automatic. Digital and environmental initiatives may develop independently, generating organisational frictions and adjustment costs that limit their integration and potential productivity benefits (Bressanelli et al., 2022; Chauhan et al., 2022; Miró-Pérez et al., 2026).

An important challenge therefore concerns the organisational coordination of digital and environmental transformations. In this study, coordination refers to the organisational process through which digitalisation and sustainability activities are connected and aligned, rather than their simultaneous adoption. Crucially, the empirical variable BFCOO, obtained from the 2022 Spanish Survey of Business Strategies (ESEE), does not directly measure coordination capability. Instead, it captures firms’ perceived barrier arising from a lack of coordination between digital technologies and sustainability. Coordination capability represents the underlying organisational capacity to connect both transformations, whereas BFCOO measures perceived difficulties in achieving this connection. Such barriers are conceptually distinct from obstacles to adopting digital technologies or environmental practices independently.

Although previous research has examined digitalisation and sustainability separately (Hermundsdottir & Aspelund, 2021; Gaglio et al., 2022), the emerging Twin Transition literature has primarily emphasised technological complementarities and operational mechanisms supporting circularity and resource efficiency (Bai et al., 2022; Chauhan et al., 2022). Less attention has been devoted to the organisational constraints affecting their coordination. Firms may invest in both transformations without developing the structures, competencies, or strategic mechanisms required to integrate them effectively.

Two organisational dimensions are particularly relevant. First, workforce skills and managerial capabilities enable firms to connect technological opportunities with environmental objectives across organisational functions (Jankowska et al., 2023; Anshari & Ordóñez de Pablos, 2025). Second, business-model characteristics may facilitate or constrain the integration of digital technologies with sustainability-oriented value creation (Kristoffersen et al., 2020; Bressanelli et al., 2022). Furthermore, formalising a sustainability strategy does not necessarily imply effective coordination with digital transformation. Strategic commitment and organisational integration represent conceptually distinct dimensions that may not develop simultaneously (Dyllick & Muff, 2016; Bañón-Gomis et al., 2025).

Against this background, the study addresses the following research question: How are workforce capability gaps and business-model constraints associated with digital-sustainability coordination barriers in Spanish manufacturing firms, and how are these barriers related to the formalisation of sustainability strategies? Using firm-level data from the 2022 ESEE, we examine the associations between skills shortages and coordination barriers (H1), business-model constraints and coordination barriers (H2), and coordination barriers and sustainability strategy (H3). The respective estimation samples comprise 265, 248, and 253 manufacturing firms, with sample construction detailed in Section 3.1.

This study makes three contributions. First, it provides firm-level evidence on perceived organisational barriers to coordinating digital and green transformations, moving beyond their simultaneous adoption. Second, it distinguishes coordination barriers from general digitalisation and sustainability barriers and from the underlying organisational capability to coordinate both domains. Third, it examines the relationship between coordination barriers and sustainability-strategy formalisation, recognising that strategic commitment does not necessarily imply organisational integration. Together, these contributions position the Twin Transition as an organisational coordination challenge rather than solely a technological or environmental transformation.

2. Literature review and hypothesis development

2.1. The Twin Transition: Synergies and tensions from a Resource- and Capability-Based perspective and the adjustment costs approach

The Twin Transition emphasises the potential complementarities between digital transformation and environmental sustainability, although their simultaneous implementation does not guarantee organisational integration (Miró-Pérez et al., 2026). From a resource- and capability-based perspective (RBV), Industry 4.0 technologies, including smart sensors, cyber-physical systems, and cloud computing, constitute valuable resources that can support circular economy practices and sustainable competitive advantage (Kristoffersen et al., 2020; Xu et al., 2023). These technologies can facilitate resource optimisation, asset life-cycle extension, and circular production processes (Siakas et al., 2023).

However, an adjustment-cost perspective highlights the organisational tensions involved in combining both transformations. Eco-innovation and digitalisation may require substantial investments, process redesign, and changes in established routines, generating temporary inefficiencies and short-term productivity losses (Li et al., 2020; Bhatia & Kumar, 2022). Evidence from Spanish manufacturing firms indicates that environmental investments may negatively affect short-term productivity before their potential benefits materialise (Miró-Pérez et al., 2026).

These perspectives suggest that the benefits of the Twin Transition depend on firms' ability to coordinate digital and environmental initiatives. Fragmented implementation may increase organisational complexity, strain absorptive capacities, and generate additional adjustment costs (Chauhan et al., 2022). Consequently, realising potential complementarities requires not only technological and environmental resources but also organisational mechanisms capable of aligning both transformation processes (Yang & Yee, 2022; Ferreira et al., 2023).

2.2. Determinants of the Digital-Sustainability coordination barrier: Skill gaps and business model incompatibility

Organisational barriers to coordinating digitalisation and sustainability include workforce capability gaps and business-model constraints (Elhusseiny & Crispim, 2022). Integrating Industry 4.0 technologies with circular economy practices requires hybrid competencies combining digital expertise, environmental knowledge, and managerial capabilities (Jankowska et al., 2023; Kumar et al., 2023). Beyond implementing each transformation independently, firms must connect technological information with sustainability objectives through cross-functional communication and coordinated decision-making (Anshari & Ordóñez de Pablos, 2025).

Skills shortages, captured by BFHA in the ESEE, may hinder this integration by limiting communication between technical and environmental functions. Without adequate managerial and technical competencies, firms may struggle to translate digital capabilities into circular economy objectives, increasing perceived digital-sustainability coordination barriers (BFCOO) (Siakas et al., 2023). Nevertheless, this association may depend on existing capabilities, external expertise, and organisational arrangements. Skills shortages are therefore expected to increase coordination difficulties rather than inevitably prevent integration (Miró-Pérez et al., 2026).

Business-model characteristics represent a second potential constraint. Circular economy practices often require changes in production processes, value creation, and organisational routines (Pieroni et al., 2019). When existing business models remain oriented towards linear production, digital technologies may primarily improve operational efficiency without supporting sustainability integration (Bressanelli et al., 2022; Chauhan et al., 2022).

Two related but conceptually distinct barriers are considered. BIMNE captures perceived incompatibility with the firm's existing business model, whereas BFPRE reflects the lack of sustainability integration into that model. Operational incompatibility does not necessarily imply insufficient sustainability integration, nor does the absence of incompatibility guarantee such integration. Their associations with coordination barriers may therefore differ depending on sectoral conditions, organisational capabilities, and the extent of transformation required (Fan et al., 2025).

Consequently, skills gaps and business-model constraints may increase the perceived difficulty of connecting digital and environmental transformations, although their effects are not assumed to be universal. The hypotheses concern associations with the perceived coordination barrier (BFCOO), rather than direct measures of coordination capability.

Hypothesis 1

(H1): The perceived barrier arising from a lack of managerial and technical workforce skills (BFHA) is positively associated with the likelihood of experiencing a lack of coordination between digital technologies and sustainability (BFCOO) in manufacturing firms.

Hypothesis 2

(H2): The incompatibility of the firm's business model with circular economy requirements (BIMNE/BFPRE) is positively associated with the likelihood of experiencing a digital-sustainability coordination barrier (BFCOO).

2.3. The relationship between coordination barriers and formalised sustainability strategy (AESOS)

Digital-sustainability coordination barriers (BFCOO) may constrain firms' ability to formalise sustainability strategies (AESOS). Strategic environmental management requires coherent objectives, governance mechanisms, and organisational commitment beyond isolated environmental practices (Eccles et al., 2014; Dyllick & Muff, 2016). A formalised sustainability strategy can provide a framework for resource efficiency, recycling, energy transition, and eco-innovation (Miró-Pérez et al., 2026).

Coordination difficulties may hinder strategic formalisation by increasing organisational uncertainty, internal transaction costs, and difficulties in aligning digital investments with environmental objectives (Bressanelli et al., 2022; Elhusseiny & Crispim, 2022). Consequently, firms experiencing such barriers may postpone sustainability strategies or rely on fragmented environmental initiatives (Kiefer et al., 2021).

However, this relationship may depend on governance arrangements and external pressures. Formal sustainability strategies may themselves facilitate coordination by clarifying responsibilities and aligning organisational priorities. Thus, coordination barriers do not necessarily prevent strategic formalisation, and the expected negative association should be interpreted as a theoretical proposition rather than a deterministic relationship.

Hypothesis 3

(H3): The presence of a barrier arising from a lack of coordination between digital technologies and sustainability (BFCOO) is negatively associated with the likelihood that a manufacturing firm has a formalised sustainability strategy (AESOS).

3. Methodology

3.1. Data and sample

The empirical analysis uses firm-level data from the 2022 Spanish Survey of Business Strategies (ESEE), which provides information on manufacturing firms' productive characteristics, technological adoption, environmental practices, organisational capabilities, and business strategies.

The initial sample comprises 1,231 firms. The models include common controls for firm size, digital intensity, environmental investment and expenditure, and technological intensity. Of the initial sample, 422 firms (34.3%) have valid information for these common variables, while 809 are excluded. The largest reduction is associated with lnGTID, available for only 433 firms. Additional

exclusions arise from missing environmental investment and expenditure data and non-substantive “don't know/no answer” responses.

The final estimation samples comprise 265 firms for H1 (BFCOO, BFHA, lnGTID, MEDINV, and MEDGAS), 248 for H2 (BFCOO, BIMNE, BFPRE, lnGTID, MEDINV, and MEDGAS), and 253 for H3. For H3, 283 firms initially meet the variable-availability requirements, but 30 are excluded because of non-substantive AESOS responses. The digitalisation index and technological-sector classification do not further reduce these samples.

To assess sample attrition, Appendix A compares the 422 retained firms with the 809 excluded firms. Retained firms are significantly larger and differ in environmental investment (MEDINV), expenditure (MEDGAS), and technological-sector composition (Pearson $\chi^2(3) = 46.74$). These differences indicate non-random attrition with respect to observable characteristics, limiting the representativeness of the estimation samples.

All models are estimated at the firm level using heteroskedasticity-robust standard errors, without ESEE sampling weights or explicit survey-design adjustments.

3.2. Variables and operationalization

The empirical analysis examines three dimensions of the digital-sustainability transition: organisational capabilities, business-model barriers, and sustainability-strategy implementation.

For H1 and H2, the dependent variable is the perceived digital-sustainability coordination barrier (BFCOO). The original ESEE codes indicating the absence of this barrier are combined into a binary reference category (0), while its presence is coded as 1. Non-substantive responses are treated as missing.

H1 examines skills shortages, including managerial and management skills (BFHA), coded as a binary indicator of the absence (0) or presence (1) of the reported barrier.

H2 considers two distinct business-model barriers: incompatibility with the existing business model (BIMNE) and lack of sustainability integration into the business model (BFPRE). Both are binary indicators, with 1 denoting the presence of the corresponding barrier. They are examined separately and jointly to distinguish their associations with BFCOO.

For H3, BFCOO is the explanatory variable, while sustainability-strategy implementation (AESOS) is the ordinal dependent variable. AESOS retains four substantive categories: no sustainability strategy, planned but not implemented, implemented internally, and implemented with external agents. Non-substantive responses are excluded. Table 1 details the original survey items, coding, analytical transformations, reference categories, and missing-value treatment.

Table 1
Definition and operationalization of the principal variables.

(Source: Authors' own elaboration)

Variable	Role in the analysis	Original ESEE survey item	Original response categories and coding	Analytical coding	Reference category	Scale direction	Missing / non-applicable treatment
BFCOO	Dependent variable in H1 and H2	Sin coordinación entre los usos de tecnologías digitales y de sostenibilidad	No = 0 or 1; Sí = 4; NS/NC = 6	Binary: 0 = No; 1 = Yes	No (0)	1 indicates the presence of a coordination barrier	NS/NC (6) treated as missing; system-missing values excluded
BFHA	Main explanatory variable in H1	Falta de habilidades, incluidas habilidades directivas y de gestión	No = 0 or 1; Sí = 4; NS/NC = 6	Binary: 0 = No; 1 = Yes	No (0)	1 indicates the presence of a skills barrier	NS/NC (6) treated as missing; system-missing values excluded
BIMNE	Explanatory variable in H2	Incompatibilidad con el modelo de negocio actual de la empresa	No = 0 or 1; Sí = 4; NS/NC = 6	Binary: 0 = No; 1 = Yes	No (0)	1 indicates the presence of a business-model incompatibility barrier	NS/NC (6) treated as missing; system-missing values excluded
BFPRE	Explanatory variable in H2	Sin integrar la sostenibilidad en el modelo de negocio de la empresa	No = 0 or 1; Sí = 4; NS/NC = 6	Binary: 0 = No; 1 = Yes	No (0)	1 indicates the absence of sustainability integration into the business model	NS/NC (6) treated as missing; system-missing values excluded
AESOS	Dependent variable in H3	Estrategia de sostenibilidad	No = 1; Práctica programada pero no realizada = 2; Práctica realizada internamente = 3; Práctica en colaboración con agentes externos = 4; NS/NC = 6	Ordered: 1–4 retained; 6 = missing	1 = No sustainability strategy/practice	Higher categories correspond to progressively implemented forms of the sustainability practice	NS/NC (6) treated as missing; system-missing values excluded

Notes

The table reports the original coding of the 2022 ESEE survey variables and their analytical recoding. For BFCOO, BFHA, BIMNE, and BFPRE, the two original database codes labelled "No" (0 and 1) are collapsed into a single reference category coded 0, while "Sí" (4) is recoded as 1. The original "NS/NC" category (6) is treated as missing and is not interpreted as a substantive response. AESOS retains its four substantive response categories (1–4), while "NS/NC" (6) is treated as missing. System-missing observations are also excluded from the corresponding econometric specifications.

The models include firm- and industry-level controls. Firm size is measured by the logarithm of employment (ln_SIZE), while lnGTID captures gross expenditure on R&D and technological activities. Environmental investment (MEDINV) and expenditure (MEDGAS) account for environmental activities. Technological-sector classification (SECTOR_TECH) distinguishes low-, medium-low-, medium-high-, and high-technology industries, using low technology as the reference category.

Multicollinearity was assessed through pairwise correlations, variance inflation factors (VIFs), and tolerance statistics. The maximum correlation was 0.64; VIFs ranged from 1.06 to 2.50 (mean = 1.38), and tolerance values from 0.40 to 0.94. These diagnostics indicate no substantial multicollinearity concerns (Appendix B).

3.3. Descriptive statistics and bivariate relationships

Descriptive statistics and frequency distributions of the principal variables are reported in Appendix C (Table C1), including the four substantive categories of sustainability strategy (AESOS).

Bivariate analyses show significant associations between the coordination barrier (BFCOO) and both skills shortages (BFHA; $\chi^2(1) = 18.85$, $p < .001$) and lack of sustainability integration into the business model (BFPRE; $\chi^2(1) = 27.88$, $p < .001$). Conversely, business-model incompatibility (BIMNE) is not significantly associated with BFCOO ($\chi^2(1) = 2.07$, $p = .150$). BIMNE and BFPRE are significantly associated with each other ($\chi^2(1) = 19.73$, $p < .001$).

These associations do not establish construct equivalence or distinctiveness. BIMNE and BFPRE are therefore treated as conceptually distinct business-model barriers, with their joint inclusion in H2 assessing their conditional associations with BFCOO.

3.3. The digital transformation index

The digital transformation index combines firm-level indicators of digital technologies, automation, digital capabilities, and digital interactions with external agents, following the multidimensional approach of Añón-Higón and Bonvin (2023), adapted to the ESEE variables.

Continuous indicators are normalised to a 0–1 scale using min–max transformation, while binary variables retain their original coding and categorical indicators are rescaled accordingly. The normalised components are aggregated using an equally weighted arithmetic mean, preventing differences in measurement units from influencing the index. Higher values indicate greater digital engagement.

The index is calculated as the mean of available normalised indicators for each firm using data from the 2022 survey wave, without temporal interpolation. Appendix D details the construction procedure and the correspondence between the original conceptual dimensions and the ESEE indicators.

3.4. Econometric Strategy

The empirical strategy is determined primarily by the measurement level of the dependent variables used in each hypothesis. Because the coordination-barrier outcome used in H1 and H2 is analytically coded as a binary indicator, binary response models are employed for these hypotheses. In contrast, the sustainability-strategy outcome used in H3 retains its four substantive ordered categories and is therefore analysed using ordered response models.

For H1 and H2, the baseline specification is a probit model. Let Y^*_i denote the latent propensity of firm i to report the outcome of interest. The latent-variable model can be expressed as:

$$Y^*_i = \alpha + \beta X_i + \gamma' C_i + \varepsilon_i$$

where X_i represents the main explanatory variable(s), C_i is a vector of control variables, and ε_i is an error term assumed to follow a standard normal distribution. For the binary outcomes used in H1 and H2, the observed outcome Y_i takes the value 1 when the coordination barrier is reported and 0 otherwise.

For H1, the probit model estimates the relationship between the presence of a lack of skills, including managerial and management skills (BFHA_bin), and the presence of a digital-sustainability coordination barrier (BFCOO_bin). The specification is:

$$BFCOO^*_i = \alpha + \beta_1 BFHA_i + \gamma' C_i + \varepsilon_i$$

H1 is supported if $\beta_1 > 0$, indicating that firms reporting a lack of skills are more likely to report a digital-sustainability coordination barrier.

For H2, the binary response specification relates business-model barriers to the digital-sustainability coordination outcome. The general specification is:

$$BFCOO^*_i = \alpha + \beta_1 BIMNE_i + \beta_2 BFPRE_i + \gamma' C_i + \varepsilon_i$$

where BIMNE captures incompatibility with the firm's current business model and BFPRE captures the lack of integration of sustainability into the business model. These two dimensions are estimated both separately and jointly in order to distinguish their individual associations with the coordination barrier and assess whether the results for either dimension remain when both are considered simultaneously. H2 is supported when the estimated coefficients are positive, indicating a higher probability of reporting digital-sustainability coordination barriers among firms facing business-model-related barriers.

For H3, the specification models the firm's sustainability strategy as a function of the presence of a digital-sustainability coordination barrier. Because the sustainability-strategy variable retains four substantive ordered categories, an ordered probit model is used as the baseline specification. Let Y^*_i denote the latent propensity of firm i to report a higher level of the relevant outcome. The model can be expressed as:

$$Y^*_i = \alpha + \beta X_i + \gamma' C_i + \varepsilon_i$$

where X_i represents the main explanatory variable, C_i is a vector of control variables, and ε_i is assumed to follow a standard normal distribution. The observed ordinal outcome Y_i is determined by a set of threshold parameters. Specifically, the observed outcome takes category j when:

$$\kappa_{j-1} < Y^*_i \leq \kappa_j$$

For H3, the specification is:

$$AESOS^*_i = \alpha + \beta_1 BFCOO_i + \gamma' C_i + \varepsilon_i$$

where AESOS retains its four substantive categories, ranging from no sustainability strategy to implementation with external agents, while the original NS/NC category is treated as missing. The hypothesis predicts a negative relationship ($\beta_1 < 0$), implying that coordination difficulties between digital technologies and sustainability are associated with a lower level of sustainability strategy.

For the ordered probit and ordered logit specifications, the common-threshold (parallel-lines) assumption implies that the effect of each explanatory variable is constant across the cumulative thresholds separating the ordered outcome categories. This assumption is relevant because relaxing it allows the association between an explanatory variable and the outcome to differ across thresholds. For H3, the assumption is assessed using a formal parallel-lines diagnostic for the ordered-logit specification. The diagnostic provides mixed evidence across alternative test statistics, with some tests rejecting and others not rejecting the parallel-lines restriction. Accordingly, the assumption is not treated as unambiguously satisfied. A generalized ordered logit specification was therefore also examined to assess whether allowing threshold-specific effects materially affected the results.

The generalized ordered logit estimation did not achieve stable convergence and produced numerical problems, including a non-positive or highly singular variance matrix and invalid predicted probabilities. It was therefore not considered sufficiently reliable for substantive inference. The ordered logit model is consequently retained as the principal robustness specification because it converges satisfactorily and provides stable estimates, while the diagnostic and generalized ordered-logit exercise are reported as specification checks rather than as alternative substantive estimates.

3.5. Robustness checks and marginal effects

Robustness is assessed using binary logit models for H1 and H2 and an ordered logit specification for H3, allowing comparison with the baseline probit models under alternative distributional assumptions. For H3, the parallel-lines assumption and the numerical limitations of the generalized ordered logit are addressed in Section 3.4.

An additional sensitivity analysis recodes sustainability strategy into a binary outcome distinguishing implemented strategies (AESOS ≥ 3) from absent or planned-but-not-implemented strategies (AESOS < 3), estimated using probit and logit models.

Average marginal effects and predicted probabilities facilitate interpretation of the nonlinear models. For H1, these quantify the association between skills shortages (BFHA) and coordination barriers (BFCOO). For H2, they assess BIMNE and BFPRE separately and jointly. For H3, marginal effects are calculated for the highest sustainability-strategy category (AESOS = 4), alongside predicted probabilities for all four categories.

All specifications employ heteroskedasticity-robust standard errors, with statistical significance assessed at conventional levels.

4. Results

This section presents the empirical results for the three hypotheses, using estimation samples of 265 firms for H1, 248 for H2, and 253 for H3. H1 and H2 are examined using probit models with logit robustness checks. For H3, ordered logit and ordered probit specifications are reported, alongside proportional-odds diagnostics and sensitivity analyses. Generalized ordered logit estimates are excluded from substantive interpretation because of convergence and numerical instability.

All models include firm-level controls for size, technological and digital capabilities, environmental investment and expenditure, and technological sector, with heteroskedasticity-robust standard errors.

The results are presented sequentially: skills shortages and coordination barriers (H1), business-model constraints and coordination barriers (H2), and the relationship between coordination barriers and sustainability strategy (H3). Marginal effects and predicted probabilities complement the coefficient estimates.

4.1. Skills Shortages and the Digital-Sustainability Coordination Barrier

Table 2 presents the results for H1, showing a positive and statistically significant association between skills shortages (BFHA) and digital-sustainability coordination barriers (BFCOO). The probit coefficient is 0.843 ($p < .01$), while the logit coefficient is 1.488 ($p < .01$), confirming the consistency of the association across specifications.

Marginal effects (Table 2A) indicate a substantively relevant relationship. In the probit model, the predicted probability of reporting a coordination barrier increases from 62.45% among firms without skills shortages to 86.88% among those reporting shortages, a difference of 24.43 percentage points. The logit model produces similar estimates (62.35% and 87.04%, respectively). Average marginal effects are positive and statistically significant in both specifications.

Regarding control variables, environmental investment (MEDINV) and high-technology sector membership are negatively and significantly associated with coordination barriers, while most other controls are not statistically significant.

Overall, the findings support H1, suggesting that workforce capability gaps are associated with greater perceived difficulties in coordinating digitalisation and sustainability. However, given the cross-sectional design, these relationships should be interpreted as conditional associations rather than causal effects.

Table 2
Skills Shortages and the Digital-Sustainability Coordination Barrier.

(Source: Authors' own elaboration) **Notes**: Robust standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. The dependent variable is the binary indicator of the digital-sustainability coordination barrier (BFCOO_bin). The reference category for technology intensity is low technology.

Skills shortage (BFHA_bin)	**(1) Probit**	**(2) Logit**
	0.843* **	**1.488*** **
	(0.212)	(0.370)
ln(Size)	-0.069	-0.114
	(0.094)	(0.167)
ln(GTID)	0.059	0.098
	(0.057)	(0.098)
Digitalisation index	0.656	1.411
	(0.772)	(1.390)
MEDINV	-0.577**	-1.029**
	(0.292)	(0.494)
MEDGAS	-0.021	0.029
	(0.250)	(0.458)
Medium-low technology	-0.001	0.026
	(0.267)	(0.490)
Medium-high technology	-0.215	-0.391
	(0.234)	(0.421)
High technology	-1.212***	-2.130***
	(0.442)	(0.738)
Constant	0.388	0.475
	(0.845)	(1.496)
Observations	265	265
Pseudo R^2	0.111	0.114
Wald chi^2	27.15	27.15
Prob > chi^2	0.0013	0.0013
Log pseudolikelihood	-111.407	-111.069

Table 2
A. Marginal Effects and Predicted Probabilities for H1.

(Source: Authors' own elaboration)

Average marginal effect of BFHA_bin	**Probit**	**Logit**
	0.198* **	**0.193*** **
Robust SE	(0.046)	(0.043)
p-value	< 0.001	< 0.001
P(BFCOO = 1 | BFHA = 0)	62.45%	62.35%
P(BFCOO = 1 | BFHA = 1)	86.88%	87.04%
Difference (percentage points)	+ 24.43	+ 24.69

Notes

Average marginal effects are calculated using robust standard errors. Predicted probabilities are evaluated at BFHA = 0 and BFHA = 1 while averaging over the observed values of the remaining covariates. * p < 0.10, ** p < 0.05, *** p < 0.01.

4.2. Business-Model Incompatibility and the Digital-Sustainability Coordination Barrier

Table 3 presents the results for H2, providing partial support for the hypothesis. Business-model incompatibility (BIMNE) is not statistically significant in either the separate or joint specifications. Its probit coefficients are 0.225 and − 0.037, respectively, while the corresponding logit estimates are 0.383 and − 0.083. These results do not establish a statistically significant association with coordination barriers, although they do not rule out a relationship.

Conversely, the lack of sustainability integration into the business model (BFPRE) is positively and significantly associated with coordination barriers. Its probit coefficient is 0.802 ($p < .001$), remaining virtually unchanged in the joint specification (0.809). The corresponding logit coefficients are 1.394 and 1.410, both significant at the 1% level.

These findings highlight the distinction between BIMNE, which captures perceived incompatibility with the existing business model, and BFPRE, which measures the lack of sustainability integration into that model. Although related, these dimensions are not interchangeable, and their associations with coordination barriers differ.

Marginal effects reinforce these findings. In the separate probit specification, BFPRE is associated with an average marginal effect of approximately 17.4 percentage points, while predicted probabilities increase from 69.3% to 89.7% when the barrier is present. The joint specification yields a similar marginal effect (17.5 percentage points). BIMNE's marginal effects remain statistically insignificant.

Among control variables, high-technology sector membership is negatively associated with coordination barriers, while lnGTID is positively significant in several specifications. The digitalisation index is not statistically significant.

Overall, H2 receives partial support: insufficient sustainability integration is significantly associated with coordination barriers, whereas business-model incompatibility is not. These cross-sectional associations do not establish causality, and the non-significant BIMNE results should not be interpreted as evidence that business-model incompatibility is irrelevant.

Table 3
Business-Model Incompatibility and the Digital-Sustainability Coordination Barrier

	(1) BIMNE	(2) BFPRE	(3) BOTH	(4) BIMNE	(5) BFPRE	(6) BOTH
	Probit	Probit	Probit	Logit	Logit	Logit
Business-model incompatibility (BIMNE)	0.225		-0.037	0.383		-0.083
	(0.264)		(0.288)	(0.472)		(0.506)
Lack of sustainability integration (BFPRE)		0.802***	0.809***		1.394***	1.410***
		(0.196	(0.204		(0.353)	(0.365)
ln(Size)	-0.041	-0.072	-0.072	-0.063	-0.113	-0.114
	(0.093)	(0.101)	(0.101)	(0.162)	(0.185)	(0.185)
ln(GTID)	0.124**	0.123**	0.124**	0.215**	0.202*	0.204*
	(0.058)	(0.061)	(0.061)	(0.098	(0.107)	(0.108)
Digitalisation index	0.488	0.542	0.552	0.876	1.035	1.062
	(0.797)	(0.816)	(0.831)	(1.452)	(1.485)	(1.516)
MEDINV	-0.495	-0.449	-0.45	-0.892*	-0.816	-0.819
	(0.304)	(0.309)	(0.309)	(0.504)	(0.52)	(0.522)
MEDGAS	0.155	0.243	0.24	0.276	0.386	0.383
	(0.254)	(0.261)	(0.259)	(0.472)	(0.478)	(0.476)
Medium-low technology	-0.019	-0.109	-0.107	(0.016	-0.107	-0.104
	(0.262)	(0.274)	(0.273)	(0.475)	(0.494)	(0.493)
Medium-high technology	-0.185	-0.354	-0.354	(0.34	-0.528	-0.527
	(0.237)	(0.235)	(0.236)	(0.431)	(0.43)	(0.431)
High technology	-1.417***	-1.292***	-1.284***	-2.415***	-2.144***	-2.128***
	(0.486)	(0.457)	(0.459)	(0.793)	(0.77)	(0.773)
Constant	-0.279	-0.527	-0.508	-0.537	-0.866	-0.837
	(0.905)	(0.935)	(0.934)	(1.563)	(1.629)	(1.623)
Observations	248	248	248	248	248	248
Pseudo R^2	0.063	0.123	0.123	0.063	0.122	0.122
Wald χ^2	14.74	35.28	35.35	15.33	35.01	35.04
Prob > χ^2	0.098	< 0.001	< 0.001	0.082	< 0.001	< 0.001

(Source: Authors' own elaboration)

Notes

Robust standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. The dependent variable is the binary indicator of the digital-sustainability coordination barrier (BFCOO_bin). The reference category for technology intensity is low technology. Columns (1) and (4) include business-model incompatibility (BIMNE_bin) only; columns (2) and (5) include lack of sustainability integration (BFPRE_bin) only; columns (3) and (6) include both variables simultaneously.

4.3. Coordination Barriers and Sustainability Strategy

H3 examines whether digital-sustainability coordination barriers (BFCOO) are negatively associated with sustainability-strategy implementation (AESOS). The ordered probit model serves as the baseline specification, with ordered logit and binary-response models providing robustness checks (Table 7).

Parallel-lines diagnostics for the ordered logit model (Table 4) yield mixed results. The Wolfe–Gould (p = 0.159) and Wald (p = 0.130) tests do not reject the restriction, whereas the Brant (p < .001), score (p = .005), and likelihood-ratio (p = .001) tests reject it. Thus, the proportional-odds assumption cannot be regarded as unequivocally satisfied.

Table 4
Tests of the Parallel-Lines Assumption for the Ordered Logit Model.

(Source: Authors' own elaboration)

Test	Chi²	df	p-value	Conclusion
Wolfe–Gould	23.89	18	0.159	Do not reject
Brant	551.30	18	< 0.001	Reject
Score	37.47	18	0.005	Reject
Likelihood ratio	44.02	18	0.001	Reject
Wald	24.81	18	0.130	Do not reject

Notes

The null hypothesis is that the regression coefficients are equal across the cumulative thresholds of the ordered logit model. A p-value below 0.05 indicates rejection of the parallel-lines assumption.

A generalized ordered logit model was also examined to address the proportional-odds concerns but was excluded from substantive inference because of convergence problems, a singular variance matrix, and invalid predicted probabilities. The analysis therefore relies on ordered probit as the baseline specification and ordered logit as a robustness check, both estimated using 253 observations and the same set of controls.

Table 5
Coordination Barriers and Sustainability Strategy.

(Source: Authors' own elaboration)

Variables	**(1) Ordered Probit (baseline)**	**(2) Ordered Logit (robustness)**
Coordination barrier (BFCOO_bin)	0.200	0.305
	(0.179)	(0.304)
ln(Size)	0.267***	0.503***
	(0.086)	(0.154)
ln(GTID)	0.067	0.103
	(0.053)	(0.091)
Digitalisation index	−0.211	−0.402
	(0.640)	(1.114)
MEDINV	−0.073	−0.084
	(0.258)	(0.428)
MEDGAS	−0.605***	−0.979***
	(0.211)	(0.364)
Medium-low technology	−0.281	−0.522
	(0.191)	(0.321)
Medium-high technology	−0.128	−0.285
	(0.176)	(0.299)
High technology	0.365	0.640
	(0.472)	(0.866)
Cut 1	1.118	2.031
	(0.701)	(1.194)
Cut 2	1.393**	2.486**
	(0.701)	(1.193)
Cut 3	2.995***	5.356***
	(0.735)	(1.269)
Observations	253	253
Wald chi-squared	48.66	46.90
Model p-value	< 0.001	< 0.001
Pseudo R^2	0.091	0.094
Log pseudolikelihood	−256.390	−255.578

Table 5

reports positive but statistically insignificant coefficients for the coordination barrier in both the ordered probit (β = 0.200, p = .263) and ordered logit (β = 0.305, p = .315) specifications. Thus, neither model supports H3. Among controls, firm size is positively significant (probit: β = 0.267, p = .002; logit: β = 0.503, p = .001), while environmental expenditure (MEDGAS) is negatively significant (probit: β = −0.605, p = .004; logit: β = −0.979, p = .007). Other controls are not statistically significant. Predicted probabilities (Table 6) show that firms reporting coordination barriers have a lower estimated probability of having no sustainability strategy (45.1% versus 52.1%) and higher probabilities of internal implementation (39.0% versus 34.1%) and implementation with external agents (6.3% versus 4.4%). However, these differences are not statistically significant. For the highest category (AESOS = 4), average marginal effects are 0.021 (p = .285) for ordered probit and 0.016 (p = .337) for ordered logit.

Sustainability-strategy category	**BFCOO = 0**	**BFCOO = 1**	**Difference (pp)**
1. No sustainability strategy	52.06%	45.07%	-6.99
2. Planned but not implemented	9.45%	9.58%	+ 0.13
3. Implemented internally	34.07%	39.01%	+ 4.94
4. Implemented with external agents	4.42%	6.34%	+ 1.92
Total	100.00%	100.00%	
Marginal effect on highest substantive category (AESOS = 4):			

Table 6

Predicted Probabilities of Sustainability-Strategy Categories by Coordination Barrier

Model	**AME**	**Robust SE**	**z**	**p-value**	**95% CI**
Ordered probit	0.021	0.020	1.07	0.285	[-0.018, 0.059]
Ordered logit	0.016	0.016	0.96	0.337	[-0.016, 0.048]

Ordered probit specification. (Source: Authors' own elaboration)

Notes

Predicted probabilities are evaluated at BFCOO = 0 and BFCOO = 1 while holding the remaining covariates at their observed values. Differences are expressed in percentage points. Robust standard errors are reported for the average marginal effects.

Although the predicted probabilities suggest a positive pattern, the estimated differences are not statistically significant. The average marginal effects for the highest sustainability-strategy category (AESOS = 4) are 2.1 percentage points in the ordered probit model and 1.6 percentage points in the ordered logit model. These results provide insufficient evidence of either a positive or negative association between coordination barriers and sustainability-strategy implementation.

The binary robustness checks (Table 7), distinguishing implemented sustainability strategies (AESOS ≥ 3) from absent or planned-but-not-implemented strategies, also yield positive but statistically insignificant associations. Average marginal effects are 0.087 (p = .248) for probit and 0.093 (p = .226) for logit. These findings reinforce the lack of empirical support for H3, although the binary specification represents a different operationalisation of the outcome.

Table 7
Robustness Checks for H3.

(Source: Authors' own elaboration)

Coordination barrier (BFCOO_bin)	**(1) Ordered Logit**	**(2) Threshold ≥ 3 Probit**	**(3) Threshold ≥ 3 Logit**
	0.305	**0.250**	**0.438**
	(0.304)	(0.219)	(0.367)
Average marginal effect	0.016	0.087	0.093
	(0.016)	(0.076)	(0.077)
p-value of AME	0.337	0.248	0.226
ln(Size)	0.503***	0.283***	0.469***
	(0.154)	(0.092)	(0.157)
ln(GTID)	0.103	0.061	0.093
	(0.091)	(0.060)	(0.101)
Digitalisation index	-0.402	-0.073	-0.068
	(1.114)	(0.717)	(1.191)
MEDINV	-0.084	0.114	0.178
	(0.428)	(0.307)	(0.499)
MEDGAS	-0.979***	-0.503**	-0.866**
	(0.364)	(0.233)	(0.400)
Medium-low technology	-0.522	-0.202	-0.316
	(0.321)	(0.216)	(0.354)
Medium-high technology	-0.285	-0.157	-0.273
	(0.299)	(0.203)	(0.334)
High technology	0.640	0.390	0.689
	(0.866)	(0.475)	(0.780)
Observations	253	253	253
Pseudo R^2	0.094	0.109	0.110
Wald chi^2	46.90	35.44	32.03
Prob > chi^2	< 0.001	< 0.001	0.0002
Log pseudolikelihood	-255.578	-154.700	-154.615

Notes

Robust standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. In columns (2) and (3), the dependent variable is a binary indicator equal to one when the sustainability strategy is implemented (AESOS ≥ 3), either internally or with external agents. Low-technology firms are the reference category.

Overall, H3 is not supported. Across the ordered probit, ordered logit, and binary robustness specifications, the estimated associations between coordination barriers and sustainability-strategy implementation are consistently statistically insignificant. These findings do not demonstrate the absence of a relationship but indicate insufficient evidence to confirm the hypothesised negative association. Sustainability-strategy implementation and digital-sustainability coordination may represent distinct

organisational dimensions, although this interpretation remains tentative given the cross-sectional design, sample size, and measurement limitations.

5. Discussion

The Twin Transition literature emphasises the potential complementarities between digitalisation and sustainability, particularly through resource optimisation, traceability, and circular production (Hoosain et al., 2023; Xu et al., 2023). However, these complementarities do not automatically emerge from pursuing both transformations simultaneously. Their integration requires organisational mechanisms connecting resources, competencies, processes, and strategic priorities.

The findings for H1 highlight the relevance of workforce competencies. Skills shortages are positively and significantly associated with perceived digital-sustainability coordination barriers, consistent with research identifying human capital as a constraint on Industry 4.0 adoption and sustainability integration (Jankowska et al., 2023; Anshari & Ordóñez de Pablos, 2025). Beyond technical specialisation, hybrid competencies may facilitate knowledge transfer between digital and environmental functions, aligning technological opportunities with sustainability objectives (Kumar et al., 2023). From a resource-based perspective, digital and environmental resources may be complementary, but their effective combination depends on organisational knowledge and integration mechanisms. The findings are consistent with this interpretation, although they do not directly measure such capabilities.

H2 provides further insight into the organisational conditions associated with coordination barriers. The lack of sustainability integration into the business model (BFPRE) is positively and significantly associated with these barriers, whereas perceived business-model incompatibility (BIMNE) is not statistically significant. This distinction suggests that reported coordination difficulties are more closely associated with insufficient sustainability integration than with perceptions of incompatibility. Nevertheless, the non-significant BIMNE estimates do not establish that incompatibility is irrelevant.

Business models shape how digital technologies contribute to sustainable value creation through mechanisms such as traceability, predictive maintenance, circularity, and product-life extension (Pieroni et al., 2019; Kristoffersen et al., 2020). Digitalisation may support environmental objectives but can also reinforce existing linear production models. Consequently, its sustainability contribution depends partly on business-model configurations and organisational processes (Bressanelli et al., 2022). The significant BFPRE association is consistent with this argument, without establishing a causal mechanism.

These findings support a conceptual distinction between digital capabilities, sustainability capabilities, and their organisational coordination. The Twin Transition can be understood as an integration challenge requiring the alignment of resources, knowledge, and practices rather than the parallel adoption of technologies and environmental initiatives. However, the present study measures perceived coordination barriers, not coordination capability itself. Its empirical contribution therefore concerns the organisational characteristics associated with reported difficulties in integrating the two transformations.

H3 introduces an additional qualification. Contrary to expectations, coordination barriers are not significantly associated with sustainability-strategy implementation across the ordered probit, ordered logit, and binary robustness specifications. Although the estimated coefficients are positive, their lack of statistical significance prevents conclusions about either a positive or negative relationship. Thus, H3 is not supported by the available evidence.

One possible interpretation is that sustainability-strategy implementation and digital-sustainability coordination represent distinct organisational dimensions. Formal sustainability strategies may establish objectives, responsibilities, and investments without necessarily ensuring integration with digital transformation (Dyllick & Muff, 2016; Sroufe, 2017). Firms may therefore implement sustainability practices while reporting coordination difficulties. However, the non-significant estimates do not demonstrate that these dimensions are independent or that formal strategies are ineffective (Siakas et al., 2023).

Similarly, coordination barriers and sustainability strategies may evolve at different rates, but the cross-sectional evidence cannot establish temporal relationships or adjustment mechanisms (Hermundsdottir & Aspelund, 2021; Torrent-Sellens et al., 2026). Longitudinal research would be necessary to determine whether changes in sustainability-strategy implementation precede, accompany, or follow changes in perceived coordination barriers.

The study makes three main theoretical contributions. First, it distinguishes the coexistence of digital and sustainability initiatives from their organisational integration. Second, it identifies skills shortages and insufficient sustainability integration into business models as significant correlates of perceived coordination barriers, while finding no significant association for perceived business-model incompatibility. Third, it differentiates sustainability-strategy implementation from digital-sustainability coordination, without assuming that either necessarily determines the other. Together, these contributions extend the Twin Transition debate towards the organisational conditions associated with integrating potentially complementary transformations.

From a managerial perspective, the findings suggest the value of complementing technological and environmental investments with workforce development, hybrid competencies, and business-model adaptation. Cross-functional teams, joint planning, and performance indicators incorporating digital and environmental objectives may help organisations address fragmentation, although their effectiveness is not directly tested here.

For policymakers, programmes supporting digital and green investments could be complemented by initiatives promoting reskilling, organisational learning, and sustainability-oriented business-model development. Supporting both transitions separately may be insufficient to address the perceived coordination difficulties identified in this study. Policies aimed at facilitating their integration should therefore consider human and organisational factors alongside technological and environmental investment.

6. Limitations

This study has several limitations. First, the cross-sectional nature of the 2022 ESEE data prevents causal inference and the identification of temporal relationships. Reverse causality and unobserved factors may influence the observed associations. Longitudinal research could examine whether skills shortages and business-model constraints precede coordination barriers or emerge during the Twin Transition.

Second, the analysis relies partly on firm-reported measures, which may be affected by perceptual differences and common-method bias, particularly because several barriers are measured using the same survey instrument. Moreover, digital-sustainability coordination is multidimensional and cannot be fully captured by the available indicators. Future studies could combine survey responses with objective measures of digital adoption, environmental performance, workforce competencies, and organisational practices, alongside more comprehensive coordination measures.

Third, the analytical samples differ across hypotheses because of missing or non-applicable responses. As shown in Appendix A, included and excluded firms differ in size, environmental investment and expenditure, and technological-sector composition. These differences raise concerns about selection bias, representativeness, statistical power, and comparability across models. Alternative specifications do not eliminate these limitations, which warrant further examination using larger and more complete datasets.

Fourth, the digitalisation index depends on methodological decisions concerning indicator selection, normalisation, aggregation, and temporal treatment. Alternative measurement approaches or weighting schemes could produce different results.

Finally, the study focuses on Spanish manufacturing firms, limiting the generalisability of its findings. Unobserved organisational and institutional factors may also remain despite the inclusion of firm-level controls. Replication across countries and sectors, preferably using longitudinal data and alternative measures, would help establish the robustness and broader applicability of the observed associations.

7. Conclusions

This study shows that the simultaneous pursuit of digitalisation and sustainability does not necessarily ensure an integrated Twin Transition. Evidence from Spanish manufacturing firms indicates that skills shortages are positively associated with perceived digital-sustainability coordination barriers (H1). Regarding business-model constraints (H2), insufficient sustainability integration is significantly associated with these barriers, whereas perceived business-model incompatibility shows no statistically significant association.

The findings also distinguish sustainability-strategy implementation from digital-sustainability coordination. Contrary to H3, the results provide no statistically significant evidence that coordination barriers are associated with lower sustainability-strategy implementation. This does not establish the absence of a relationship but suggests that formal sustainability strategies and coordination processes may represent distinct organisational dimensions.

The study contributes to understanding the Twin Transition as an organisational integration challenge rather than the coexistence of two independent transformations. Its findings highlight workforce competencies and sustainability-oriented business-model integration as relevant factors associated with perceived coordination difficulties. However, the cross-sectional design prevents causal interpretation, and coordination capability itself is not directly measured.

Ultimately, advancing the Twin Transition requires attention not only to digital and environmental investments but also to the organisational conditions that may facilitate their alignment. Developing hybrid competencies, integrating sustainability into business models, and connecting strategic priorities across functions may help firms pursue both transformations more coherently.

Declarations

Clinical trial number

Not applicable.

Ethics, Consent to Participate, and Consent to Publish declarations

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Author Contribution

A.A., B.B. and C.C. contributed equally to all stages of the research, including conceptualisation, methodology, data analysis, interpretation of results, writing of the original draft, review and editing. All authors read and approved the final manuscript.

Data Availability

The data that support the findings of this study are available from the SEPI Foundation (Fundación SEPI) through the 2022 Spanish Survey of Business Strategies (ESEE), but restrictions apply to the availability of these data, which were used under licence for the current study and are therefore not publicly available. Data are, however, available from the authors upon reasonable request and with permission from the SEPI Foundation.

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31. Appendix A. Sample construction and comparison of retained and excluded firms.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix.docx