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Heterogeneous Paths to Green Investment: how much do firms' economic conditions matter in their decision to invest in environmental innovation?

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Abstract

The green transition requires firms to undertake investments whose costs are immediate and whose returns are uncertain. Although stronger prior economic performance may ease resource constraints, weaker performance may also induce firms to seek cost reductions and resource efficiency. We examine these competing mechanisms using an original dataset of 1,537 firms in Emilia-Romagna. We combine survey data on environmental investments undertaken in 2019–2023 with balance-sheet measures of profitability, productivity and growth in 2015–2018. The empirical strategy first applies cluster analysis to identify distinct economic performance-environmental investment profiles and then estimates pairwise logit models comparing investors and non-investors with broadly comparable prior economic conditions. Four profiles emerge. Profitability, productivity and growth do not translate into a common investment pattern: some firms invest without a clear prior economic advantage, while firms with stronger profitability and growth may remain weakly engaged. Across the pairwise comparisons, regulatory knowledge, external consulting, environmental subsidies and process innovation are systematically associated with membership in the investor profiles. The results show that prior economic performance does not map onto a single green investment trajectory. Rather, firms follow heterogeneous paths shaped by the interaction of economic conditions, internal capabilities, access to knowledge and policy support.

Keywords: Eco-innovation; Green Investment; Firm Heterogeneity; Economic Performance; Cluster Analysis.

1. Introduction

In recent years, green investments have become increasingly central to debates on economic growth and competitiveness. At the European level, this orientation has been consolidated by the European Green Deal, which places the green and circular transition at the core of the European Union's long-term development strategy (European Commission, 2019). Within this policy framework, firms are increasingly expected to contribute to the transition towards more sustainable production models by undertaking investments that support the adoption of eco-innovative practices. However, this raises a relevant question: which firms are actually able and willing to undertake such environmental investments?

Green investments often require substantial upfront expenditure, technological and organisational change, and managerial capabilities, while their returns may be uncertain, particularly in the short run. Slack-resources theory and the literature on financial constraints therefore predict that firms characterised by stronger prior economic performance should be better positioned to undertake eco-innovation-related investments. Better-performing firms have more internal resources and are better able to bear the costs, the risks and the uncertainty associated with environmental innovation (Bourgeois, 1981; Ghisetti et al., 2017). Under this mechanism, the green transition may widen existing differences across firms, as economically stronger firms may be better positioned to invest, innovate, and consolidate their competitive advantage, whereas weaker firms may encounter greater barriers to environmental transformation and fall further behind.

At the same time, eco-innovation-related investments may also constitute a strategic response to weaker performance or to changing regulatory, technological, and market conditions. Several green practices are indeed directly associated with resource efficiency, energy savings, waste reduction, lower exposure to volatile input markets, and improved process organisation (Horbach et al, 2012). From this perspective, firms facing less favourable economic conditions may perceive environmental investments not only as a compliance obligation or an additional cost, but also as an opportunity to reduce inefficiencies, lower costs, and access new markets. This interpretation is consistent with the literature suggesting that environmental innovation may, under certain conditions, generate productivity and competitiveness gains rather than merely impose additional costs on firms (Porter and van der Linde, 1995; Ambec and Lanoie, 2008). According to this view, the green transition may be interpreted by some firms as a path for economic growth, adaptation or recovery from crisis.

These arguments generate competing expectations regarding the relationship between prior economic performance and engagement in eco-innovation-related investments. On the one hand, stronger performance may relax financial constraints and increase firms' capacity to invest in green practices. On the other hand, weaker performance may induce firms to search for efficiency gains, cost savings, or strategically differentiating solutions. Rather than treating these mechanisms as mutually exclusive, this paper argues that they may coexist across different segments of the firm population.

The aim of this paper is to examine how firms combine prior economic performance and eco-innovation-related investment behaviour. A substantial empirical literature examines the economic outcomes of environmental innovation, asking whether and under what conditions it is associated with improved firm performance (e.g. Vasileiou et al. 2022). Less attention has been devoted to how firms' prior economic conditions relate to their subsequent investment engagement. In addressing this gap, we move beyond the view that firms can be placed at two opposite poles: economically strong firms that invest because they have sufficient resources, and weaker firms that invest as a response to economic pressure. We argue that the relationship is more nuanced. Firms may combine economic conditions and environmental investment engagement in different ways, giving rise to a broader range of profiles. Moreover, we believe that prior economic performance may shape firms' capacity and incentives to invest, but it may not be sufficient to

explain their investment choices. We therefore examine whether other factors help distinguish firms that invest from those that remain weakly engaged despite starting from comparable economic positions.

We investigate this relationship using an original dataset of 1,537 firms in Emilia-Romagna. We first use cluster analysis to identify firm profiles combining prior economic performance and eco-innovation-related investment engagement, without imposing a predetermined relationship between the two. Building on the resulting taxonomy, we then estimate logit models comparing investor and non-investor profiles with broadly comparable prior economic conditions. This two-stage approach captures heterogeneity in the performance-investment relationship and identifies other factors associated with differences in investment engagement.

The empirical analysis focuses on firms' investments in environmental practices associated with six sustainability areas identified by the Taxonomy Regulation (Regulation (EU) 2020/852; European Parliament and Council 2020): i) climate change mitigation; ii) climate change adaptation; iii) sustainable use and protection of water and marine resources; iv) transition to a circular economy; v) pollution prevention and reduction; and vi) protection and restoration of biodiversity and ecosystems. Although the questionnaire measures investment decisions rather than realised eco-innovation outputs, the types of investments considered are intrinsically linked to the implementation of eco-innovative practices. For instance, investments aimed at reducing waste, improving resource efficiency, adopting low-carbon technologies, or introducing circular economy solutions generally require firms to modify their processes, technologies, organisational routines, or product/service design in ways that reduce environmental impacts (OECD/Eurostat, 2018; OECD, 2009). Accordingly, this study does not claim to measure realised eco-innovation outputs, but it analyses firms' allocation of resources to environmental practices and technologies that may constitute inputs to, or proxies for, eco-innovation adoption. The observed variables are therefore referred to as eco-innovation-related investments.

This paper contributes to the eco-innovation literature in two ways. First, consistent with an evolutionary perspective (e.g. Fagerberg, 2003), our analysis documents substantial heterogeneity in the relationship between prior economic performance and eco-innovation-related investment. Some firms invest despite lacking a clear prior economic advantage, while some economically stronger firms remain weakly engaged. Second, it shows that firms with broadly comparable prior economic conditions may differ markedly in their investment engagement. These differences are systematically associated with regulatory awareness, access to external expertise, public support, and process innovation.

The remainder of the paper is organised as follows. *Section 2* reviews the literature on the topic. *Section 3* describes the data and empirical methodology. *Section 4* presents the cluster taxonomy and provides both an external validation of the resulting profiles and a regression-based robustness check. *Section 5* concludes.

2.Literature review

The literature provides no unambiguous prediction about the relationship between prior economic performance and firms' engagement in eco-innovation-related investment. One strand of research emphasises the role of economic performance in determining firms' capacity to invest. According to slack-resources theory, firms possessing resources beyond those required for ordinary operations are better able to experiment, absorb risk and undertake long-term strategic initiatives (Bourgeois, 1981; Waddock and Graves, 1997). Because eco-innovation-related investments often entail substantial upfront expenditure and uncertain returns, stronger prior performance may increase firms' ability to bear their costs and risks. This argument is consistent with the literature on financial barriers to eco-innovation, which shows that limited internal funds and restricted access to external finance can hinder its adoption (Ghisetti et al., 2017; Horbach, 2019). Such constraints are likely to be particularly relevant for SMEs, for which environmental investments may represent a comparatively large financial burden (Rademaekers et al., 2011; Burlea-Schiopoiu and Mihai, 2019).

Economic pressure, however, may affect not only the resources available to firms but also their incentive to search for new solutions. The behavioural theory of the firm suggests that performance below an aspiration level can trigger problem-driven search aimed at improving existing outcomes (Cyert and March, 1963). Greve (2003), for example, documents this mechanism in firms' R&D and innovation decisions. In the environmental domain, investments may be undertaken in anticipation of lower energy and material costs, greater resource efficiency, regulatory advantages or improved market positioning (Horbach et al., 2012; Del Río et al., 2016, Zecca et al., 2026). Carfora et al. (2022) show that expectations of improved economic performance can encourage eco-innovation among innovative Italian SMEs, while Zhao et al. (2025) and Yin and Gao (2026) find that performance shortfalls can stimulate green innovation, although the response varies with the reference point and the severity of the shortfall. This mechanism is also consistent with the Porter Hypothesis, according to which environmental innovation, particularly when encouraged by well-designed regulation, can generate efficiency and competitiveness gains that at least partly offset its costs (Porter 1990; Porter, 1991; Porter and van der Linde, 1995; Ambec et al., 2013).

Prior economic performance may therefore influence firms' investment behaviour through two potentially opposing channels. Firms experiencing economic difficulties may have stronger incentives to seek efficiency gains or new market opportunities but fewer resources with which to finance the required investments. Conversely, better-performing firms may possess greater investment capacity without necessarily facing the same pressure to change their existing technologies and organisational practices. The balance between capacity and incentive may consequently differ across firms, producing multiple combinations of prior economic performance and environmental investment engagement. This makes it difficult to represent the relationship through a single linear mechanism and instead points to the usefulness of a profile-based perspective.

Prior economic performance, moreover, conditions firms' investment possibilities without fully determining their choices. Undertaking an environmental investment requires firms to recognise relevant technological, regulatory and market information, evaluate its potential value and translate it into changes in products, processes or organisational practices. These activities depend partly on firms' existing knowledge bases and

absorptive capacity, that is, their ability to recognise, assimilate and use external knowledge (Cohen and Levinthal, 1990). Empirical research generally links internally generated knowledge and absorptive capacity to eco-innovation, although the importance of different forms of knowledge varies across environmental objectives (Marzucchi and Montresor, 2017; Albort-Morant et al., 2018). R&D can contribute to this process by expanding firms' knowledge bases and strengthening the technological capabilities required to identify and implement environmental solutions (Horbach, 2008; De Marchi, 2012; Horbach et al., 2012; Cainelli et al., 2015; Marzucchi and Montresor, 2017; Demirel and Kesidou, 2019).

More broadly, firms already engaged in product or process innovation may have developed routines for assessing uncertain projects, reorganising production and integrating new technologies. Conventional innovation and eco-innovation should therefore not necessarily be treated as separate activities. Arranz et al. (2020) show that the two are related both contemporaneously and over time, while Aghion et al. (2016) document path dependence in clean innovation arising from firms' previous innovation trajectories. Accordingly, broader innovative activity may facilitate environmental investment by providing firms with organisational experience and complementary technological capabilities. At the same time, the direction of this relationship cannot be established mechanically, since conventional and environmental innovation may also be undertaken during the same period as part of a wider process of technological and organisational change.

The ability to implement environmental investments also depends on how firms organise and access specialised expertise. Dedicated environmental staff can help identify investment opportunities, interpret technical and regulatory information, coordinate different organisational functions and oversee implementation. Evidence from European SMEs indicates that the presence of workers in green jobs is positively associated with the adoption of resource-efficiency practices (Bassi and Guidolin, 2021). Environmental management systems that assign explicit responsibility for environmental issues similarly support eco-product and eco-process innovation (Huang and Xiao, 2023).

Not all firms, however, possess sufficient internal expertise, particularly when their small size makes it difficult to maintain specialised staff. External consultants and intermediaries can complement, or partly compensate for, limited internal capabilities by helping firms identify appropriate technologies, assess available incentives and manage implementation. Public and private intermediaries have been shown to facilitate eco-innovation among SMEs with limited internal resources (Klewitz et al., 2012), while external technical and business advice is associated with more extensive adoption of resource-efficiency and green practices (Bodas-Freitas and Corrocher, 2019; Aristei and Gallo, 2021). Internal environmental staff and external consulting can therefore be understood as different, potentially complementary, channels through which firms obtain the knowledge and coordination capacity required to undertake environmental investments.

These organisational capabilities interact with the institutional environment in which investment decisions are made. Awareness of environmental regulation can affect whether firms recognise emerging obligations and opportunities, while the ability to interpret regulatory information can reduce uncertainty surrounding the direction of technological change. Regulation may therefore influence investment not only by imposing

compliance costs but also by signalling future market conditions and increasing the expected value of environmental solutions (Porter and van der Linde, 1995; Horbach et al., 2012; Del Río et al., 2016). Its influence is nevertheless likely to depend on whether firms possess, or can access, the expertise required to translate regulatory information into concrete investment decisions.

Public financial support can further alter the balance between the costs and expected benefits of environmental investment. Because eco-innovation generates environmental and knowledge externalities, its private returns may be lower than its social returns, leading firms to invest less than would be socially desirable. Subsidies, tax credits and other financial incentives can reduce the initial cost and risk of investment and may therefore be particularly important when firms possess limited internal resources. Empirical evidence links public financial support to green product innovation, resource-efficiency practices and SMEs' ability to introduce eco-innovations (Stucki et al., 2018; Cecere et al., 2020; Aristei and Gallo, 2021). The magnitude of these effects nevertheless varies across policy instruments, firm characteristics and types of environmental innovation (Long and Liao, 2021; Ren et al., 2021; Shao and Chen, 2022; Zhang, 2022). Access to support may consequently help explain why firms facing broadly comparable economic conditions display different levels of environmental investment engagement.

Finally, external shocks can modify both the perceived benefits of environmental investment and the resources available to undertake it. Exposure to natural disasters may increase firms' awareness of environmental risks and the perceived value of technologies that reduce vulnerability to future events (Miao and Popp, 2014). At the same time, physical damage, operational disruption and financial losses may divert resources away from innovation. Consistent with this second mechanism, Agostino and Rondinella (2025) find that extreme climate events reduce green innovation among Italian manufacturing firms in both the short and medium term. The effect of flood exposure is therefore theoretically ambiguous: it may strengthen the incentive to undertake environmental investments while simultaneously weakening firms' capacity to finance them.

Overall, the literature suggests that eco-innovation-related investment results from the interaction between economic conditions, organisational and knowledge capabilities, external expertise, policy support and exposure to environmental shocks. These factors may reinforce or offset the influence of prior economic performance, allowing firms starting from similar economic positions to follow different investment trajectories. Against this background, the empirical analysis addresses two related questions. First, how do prior economic performance and engagement in eco-innovation-related investment combine into distinct firm profiles? Second, among profiles characterised by broadly comparable prior economic conditions, which firm internal capabilities, innovation activities, forms of external support and external conditions distinguish firms that invest from those that remain weakly engaged?

3. Empirical Analysis

3.1. Data and measures

The data sources consist of a firm-level survey conducted in Emilia-Romagna between 2023 and 2024 as part of the ECOSISTER project, subsequently merged with the AIDA database. The sample[1] comprises firms with more than five employees operating in manufacturing, utilities/water-energy supply, agriculture, construction and transport, surveyed with reference to the period 2019–2023. The original survey archive comprised 3,261 observations, which were reduced to 2,289 firms after the linking process with AIDA. The extracted variables from AIDA cover the period from fiscal year 2015 to the latest available year.

The questionnaire is structured across nine sections: Sections A–B cover firms' general information, demographics, and ownership structure; Section C focuses on workforce composition and industrial relations; Section D assesses firms' knowledge of the Taxonomy Regulation on sustainable investments; Section E investigates green investments across six environmental areas: Climate Mitigation and Adaptation, Water Management, Circular Economy, Pollution Prevention and Biodiversity, while Sections F–G examine circular economy practices, enabling and hindering factors, and related financial instruments; Section H addresses sustainability and communication; and finally, Section I covers the adoption of traditional innovations.

Our primary measure of investment is based on information collected in Section E of the questionnaire. Firms were asked whether they had undertaken investments in any of the six sustainability areas covered by the survey in the period 2019-2023. Each area includes a different number of specific investment items, for a total of thirty possible interventions (see Appendix for further details). The response options were "Yes", "No", and "Not relevant to the firm's activity". This information was used to construct six variables, one for each sustainability area, each measuring the total number of eco-innovation-related investments undertaken by the firm within a given sustainability area (*Total EI_Investments A1-A6*). In addition, to account for differences in the relevance of specific investment items across firms, we construct an overall eco-innovation-related investment propensity variable (*EI_Investments Propensity*), defined as the ratio between the number of investments undertaken, across the six sustainability areas, and the number of investment items declared relevant to the firm's activity[2].

On the economic performance side, we performed a Principal Component Analysis (PCA) using 13 balance-sheet indicators retrieved from AIDA for the period 2015–2018, hence before the investment period (More details of the PCA are presented in Appendix A.2). After the PCA, three synthetic dimensions were retained and interpreted as *Profitability*, *Productivity*, and *Growth*.

[1] The sample has been stratified by province (ISTAT classification of territorial units), sector (ATECO codes, two digits), and firm dimension (*micro*: <10 employees; *small*: 10-49 employees; *medium*: 50-249 employees; *large*: ≥ 250 employees).

[2] This ratio avoids treating firms as non-investors in areas that are not relevant to their activity.

A set of control variables is included to assess the robustness of the results. *Size* is a categorical variable capturing firms' dimension: micro firms with fewer than 10 employees, small firms with 10-49 employees, medium-sized firms with 50-249 employees, and large firms with 250 or more employees. *Sector* is a categorical variable identifying the firm's main sector of activity, distinguishing between agriculture, manufacturing, utilities/water-energy supply, construction, and transport. *Province* captures the province in which the firm operates. Managerial characteristics are controlled for through Manager's Age, a continuous variable reporting the age of the firm manager, and Manager's Education, a categorical variable capturing the manager's educational level distinguishing among lower secondary or primary education, upper secondary education or high-school diploma, three-year university degree, and university degree of at least four years or master's-level degree. *Knowledge* is a dummy variable equal to one if the firm reports being aware of the EU Taxonomy Regulation (Regulation EU 2020/852), and zero otherwise. *Consulting* is a dummy variable equal to one if the firm reports having relied on external consulting services for sustainability-related activities connected to the EU Taxonomy Regulation, and zero otherwise. *Dedicated staff* is measured as a continuous variable calculated as the ratio of employees devoting more than 50% of their working time to circular economy-related activities to the firm's total employment. Policy support is captured by *Environmental subsidies*, a dummy variable equal to one if the firm reports having used incentives for investments in assets or technologies related to the circular economy or the green transition between 2019 and 2024, and zero otherwise. Innovation activity is controlled for through two dummy variables: *Product Innovation*, equal to one if the firm introduced product innovations between 2019 and 2024, and *Process Innovation*, equal to one if the firm introduced process innovations over the same period. Finally, *Shock exposure* captures the firm's exposure to the 2023 flood event.[3] It is measured on the basis of the reported number of weeks during which the firm ceased productive activities because of the flood. In the empirical specification, the variable is coded as a dummy equal to one for firms that reported at least one week of activity suspension, and zero otherwise.

Table 1 summarizes the main data sources and the acronyms of the variables that are used throughout the paper, and it presents basic descriptive statistics for our variables of interest.

Table 1. Descriptive statistics of the main variables

Variable	Source	Years	Description	Mean	Std. Deviation
Total EI_Investments A1	Ecosister	2019-2023	N. eco-innovation-related investments – Area 1 (Climate Mitigation)	1,26	1,753
Total EI_Investments A2	Ecosister	2019-2023	N. eco-innovation-related investments – Area 2 (Climate Adaptation)	0,07	0,322

[3] The 2023 Emilia-Romagna flood occurred in two main waves, on 2–3 May and 16–17 May, and primarily affected the central-eastern part of the region. The second period of intense and persistent rainfall fell on soils already saturated by the first, leading to rapid increases in river levels, embankment failures, and extensive flooding of urban and agricultural areas. The most severe effects were concentrated in the provinces of Bologna, Ravenna, and Forlì-Cesena.

Total EI_Investments A3	Ecosister	2019-2023	N. eco-innovation-related investments – Area 3 (Water Management)	0,18	0,597
Total EI_Investments A4	Ecosister	2019-2023	N. eco-innovation-related investments – Area 4 (Circular Economy)	1,66	2,500
Total EI_Investments A5	Ecosister	2019-2023	N. eco-innovation-related investments – Area 5 (Pollution Prevention)	0,25	0,604
Total EI_Investments A6	Ecosister	2019-2023	N. eco-innovation-related investments – Area 6 (Biodiversity)	0,10	0,387
EI_Investments Propensity	Ecosister	2019-2023	Ratio between the number of eco-innovation-related investments undertaken and the number of investment relevant to the firm.	0,25	0,329
Profitability	AIDA	2015-2018	PCA score capturing pre-investment profitability	0,000	1,786
Productivity	AIDA	2015-2018	PCA score capturing pre-investment productivity	0,000	1,584
Growth	AIDA	2015-2018	PCA score capturing pre-investment growth	0,000	1,525
Size	Ecosister	2023	Firm dimension	1,822	0,762
Sector	Ecosister	2023	Firm's main sector of economic activity	2,736	1,110
Province	Ecosister	2023	Province in which the firm operates	4,401	2,572
Manager's Age	Ecosister	2023	Age of the firm manager	55,94	10,895
Managers' Education	Ecosister	2023	Educational qualification of the firm manager	2,281	0,998
Knowledge	Ecosister	2023	Firm's awareness of the EU Taxonomy Regulation	0,266	0,442
Consulting	Ecosister	2023	Use of external consulting services for sustainability-related activities linked to the EU Taxonomy Regulation.	0,165	0,371
Dedicated Staff	Ecosister	2023	Number of employees devoting more than 50% of their working time to circular economy-related activities/ total employees 2023	0,052	0,178
Environmental susbsidies	Ecosister	2019-2024	Use of public incentives for investments in circular economy or green assets and technologies.	0,070	0,255
Product Innovation	Ecosister	2019-2024	Introduction of product innovation between 2019 and 2024.	0,306	0,461
Process Innovation	Ecosister	2019-2024	Introduction of process innovation between 2019 and 2024.	0,297	0,457
Shock exposure	Ecosister	2023	Exposure to the 2023 flood causing at least one week of production shutdown	0,076	0,265

3.2 Cluster analysis methodology

The variables used to build the clusters are the following: i) sustainable investments' propensity operationalised as a cumulative relative measure in its standardized version (*zEI_Investment Propensity*); ii) the absolute number of investments undertaken within each of the six thematic areas between 2019-2023, subsequently

standardized (*zEI_Total Investments A1-6);* iii) the economic performance of the 2015-2018 period is measured through the standardized profitability index (z_*Profitability*); the standardized productivity index (z_*Productivity*) and iv) the standardized economic growth index (z_*Growth*).[4] Starting from the survey sample matched with AIDA of 2,289 firms, the cluster analysis was performed on a sample of 1,537 units, after having excluded 684 firms lacking balance sheet for the 2015-2018 period and 118 firms that declared no relevance in any of the six investment areas (50 firms met both exclusion criteria).

Cluster analysis aims to identify distinct groups of observations, in this case firm profiles, such that observations differ across clusters while remaining relatively homogeneous within each cluster. Following Hair et al. (2009), we adopt a two-step procedure to determine the optimal cluster composition. First, we apply hierarchical clustering to identify the optimal number of clusters. The hierarchical procedure was based on the average linkage algorithm, which computes the Euclidean distance in clustering variables across all possible pairs of individuals across different clusters and aims to minimize distances within the clusters and, at the same time, maximize distances across clusters. This procedure leads to the identification of four clusters through the support of a series of statistical tests (For further details on the choice of the optimal number of clusters refer to Appendix A3). With the optimal number of clusters determined a priori using the hierarchical clustering technique, the next step involved applying the k-means algorithm for non-hierarchical clustering. The centroids obtained from the hierarchical solution were used as the initial partition for the k-means procedure. This second step allows observations to be reassigned across clusters so as to improve the final partition and reduce within-cluster heterogeneity. Since k-means also relies on Euclidean distances, its use is consistent with the distance-based logic adopted in the hierarchical stage. This algorithm assigns each observation to a cluster based on similarity.

4. Results

Table 2 profiles the four clusters by reporting the mean value (and standard deviation, in parentheses) of each clustering variable, together with cluster size. For all clustering variables, one-way ANOVA indicates that differences across clusters are jointly and highly statistically significant (F-statistics ranging from 39 to 1,354, $p<0.001$), and post-hoc Scheffé comparisons show that the large majority of pairwise cluster differences are also significant; the few non-significant pairs are reported in the bottom row of the table. Because both the ANOVA F-test and Scheffé's test assume homogeneous variances across groups (an assumption violated in our data, as suggested by the cluster-specific standard deviations reported in the table), we complemented the

[4] The joint inclusion of *zEI_Investment Propensity* and the six area-specific investment variables, *zEI_Total Investments A1-6,* allows the clustering procedure to capture two distinct dimensions: 1) the relative intensity of environmental investment engagement, accounting for the number of investment items that are relevant to each firm's activity; 2) the thematic composition of such engagement across the six sustainability areas. In this way, the analysis distinguishes firms not only according to how much they invest, relative to their relevant opportunities, but also according to where their investments are concentrated.

analysis with Bartlett's test and its variant more robust to non-normality, the Brown-Forsythe test (W50); both reject the null hypothesis of equal variances for every variable, confirming that the heteroskedasticity is substantive rather than an artifact of non-normality. Nonetheless, given the magnitude of the F-statistics obtained, the differences across clusters are large enough that this violation is unlikely to affect the substantive conclusions of the analysis.

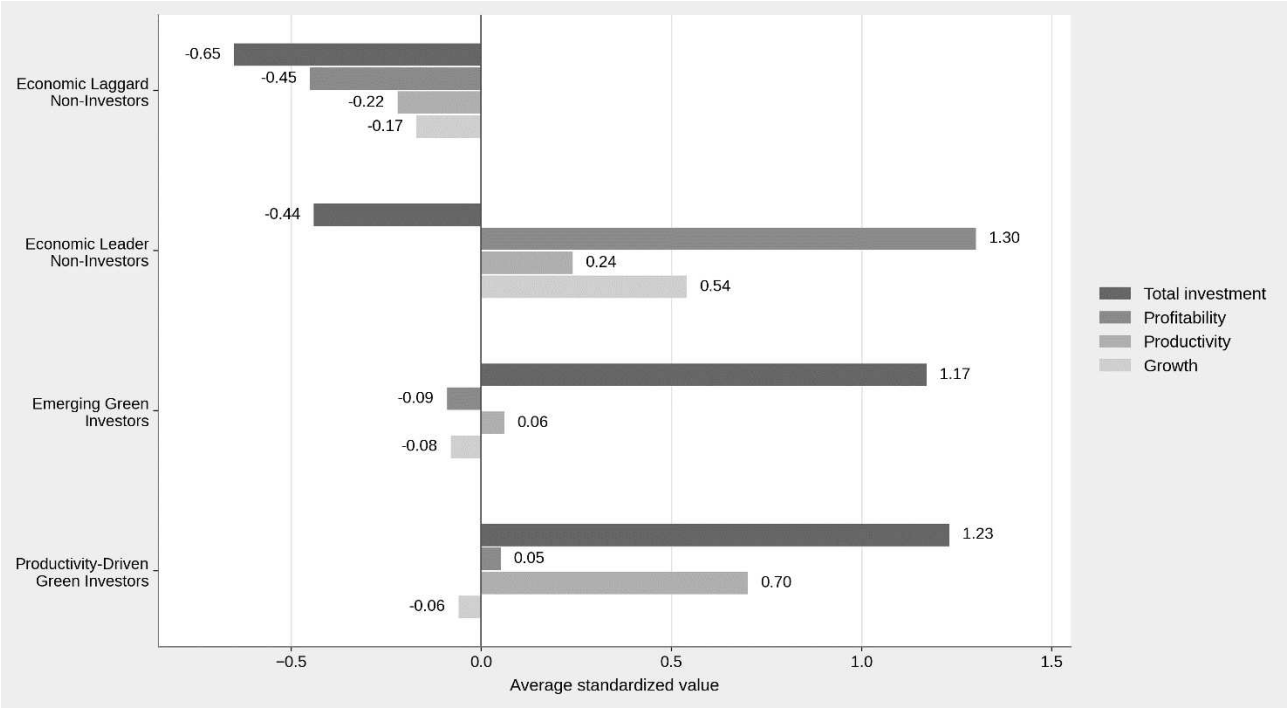
Table 2. Internal profiling of clusters- Mean values of the standardized (z-score) variables used in the cluster analysis.

Cluster	Profitability	Productivity	Growth	Climate Mitigation	Climate Adaptation	Water Management	Circular Economy	Pollution Prevention	Biodiversity	EI Investment propensity	N
Economic Laggard Non-Investors	-0.445 (0.550)	-0.219 (0.803)	-0.172 (0.574)	-0.551 (0.286)	-0.207 (0.128)	-0.258 (0.136)	-0.517 (0.283)	-0.371 (0.198)	-0.217 (0.176)	-0.654 (0.255)	721
Economic Leader Non-Investors	1.300 (0.912)	0.240 (1.203)	0.543 (1.741)	-0.374 (0.526)	-0.123 (0.546)	-0.228 (0.313)	-0.370 (0.505)	-0.319 (0.378)	-0.188 (0.330)	-0.438 (0.542)	270
Emerging Green Investors	-0.091 (0.888)	0.064 (0.982)	-0.085 (0.694)	0.983 (0.908)	-0.011 (0.805)	-0.045 (0.720)	0.891 (1.019)	0.424 (1.181)	-0.088 (0.632)	1.167 (0.771)	427
Productivity-Driven Green Investors	0.052 (1.128)	0.701 (1.247)	-0.058 (0.829)	1.765 (1.044)	2.092 (2.681)	2.504 (2.132)	1.463 (1.144)	1.677 (1.636)	2.291 (2.463)	1.226 (0.606)	119
Total	-0.002 (0.998)	0.012 (1.007)	-0.013 (0.969)	0.085 (1.034)	0.040 (1.073)	0.020 (1.022)	0.053 (1.002)	0.018 (0.993)	0.018 (1.023)	0.035 (1.002)	1537
ANOVA F-test of joint significance across clusters	332.09***	38.85***	39.83***	856.82***	232.48***	518.35***	579.03***	281.18***	365.95***	1353.51***	
Bartlett's test of equal variances (χ^2, df=3)	212.96***	92.29***	647.62***	814.74***	2900.00***	2600.00***	985.27***	1900.00***	2500.00***	661.54***	
Brown-Forsythe test of equal variances (W50)	36.84***	14.84***	30.01***	222.42***	367.25***	398.57***	289.15***	184.18***	748.85***	207.10***	
Non-significant pairs (Scheffé, p>0.05)	3–4	2–3	1–3; 1–4; 3–4	—	1–2; 2–3	1–2	—	1–2	1–2; 1–3†; 2–3	3–4	

Notes: *** p<0.001. Cluster labels: Economic Laggard Non-Investors = Cluster 1; Economic Leader Non-Investors = Cluster 2; Emerging Green Investors = Cluster 3; Productivity-driven Green Investors = Cluster 4. Both Bartlett's and Brown-Forsythe tests reject the null hypothesis of equal variances for all variables (p<0.001), confirming heteroscedasticity is substantive rather than an artifact of non-normality (see main text).

The cluster solution identifies four distinct firm profiles. Two clusters are characterised by substantial engagement in eco-innovation-related investments, whereas the remaining two display limited eco-innovation-related investments activity. However, within both the high- and low-investment groups, firms differ markedly in terms of their prior economic conditions. Cluster 1 comprises firms characterised by both weak economic conditions and low eco-innovation-related investments activity. Cluster 2 identifies firms with favourable prior economic performance but limited engagement in eco-innovation-related investments. Cluster 3 captures firms that engage in environmental investment without a distinctive prior economic advantage. Cluster 4 includes firms that combine high eco-innovation-related investments engagement with distinctly superior prior productivity.

Figure 1. Average standardized values by cluster



Source: Authors' own elaboration

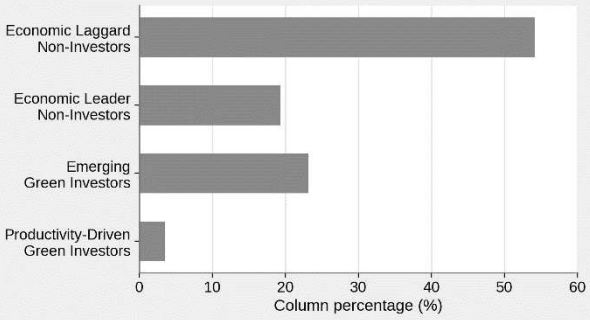
We now discuss the features of the four clusters by combining information about the clustering variables with information retrieved from the questionnaire to characterise their structural composition (**Fig. 2**).

4.1. Clusters' profiles

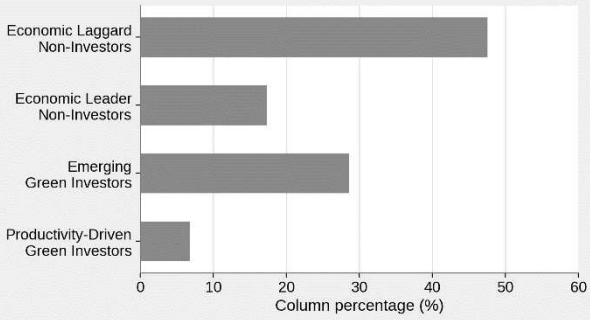
Figure 2. Cluster composition by firm size, sector and province

Firm size

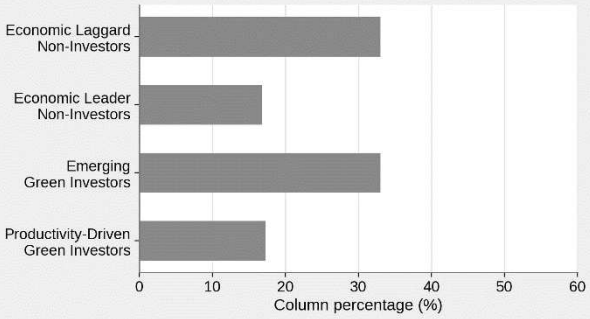
Micro



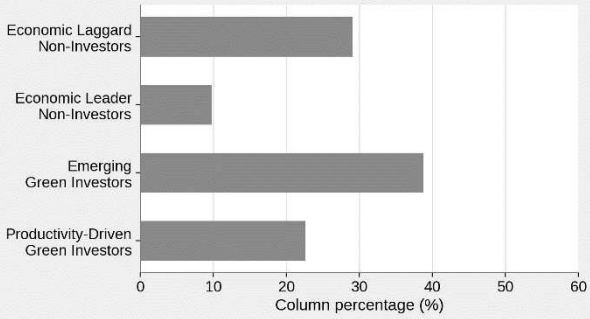
Small



Medium

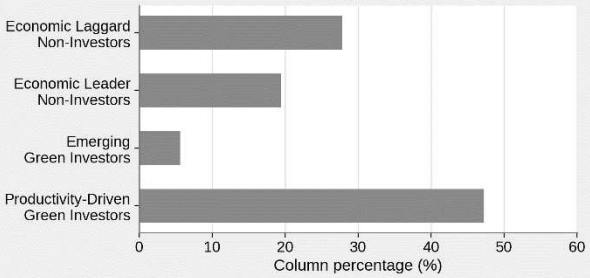


Large

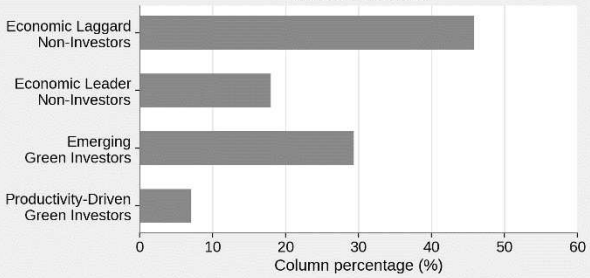


Sector

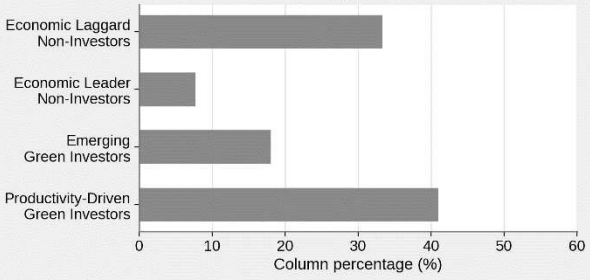
Agriculture



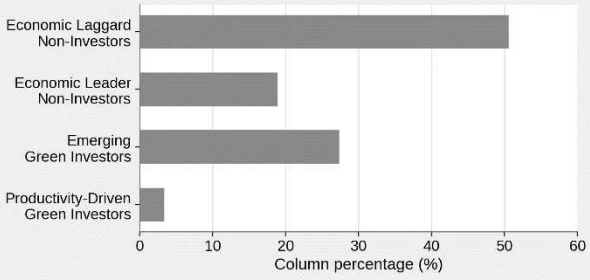
Manufacturing



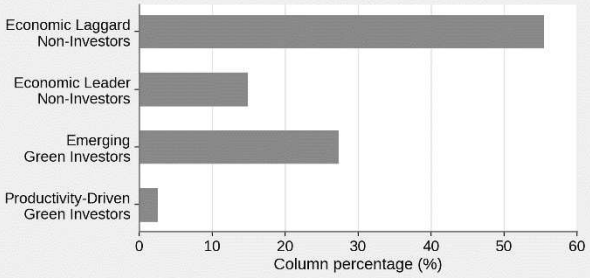
Utilities/water-energy supply

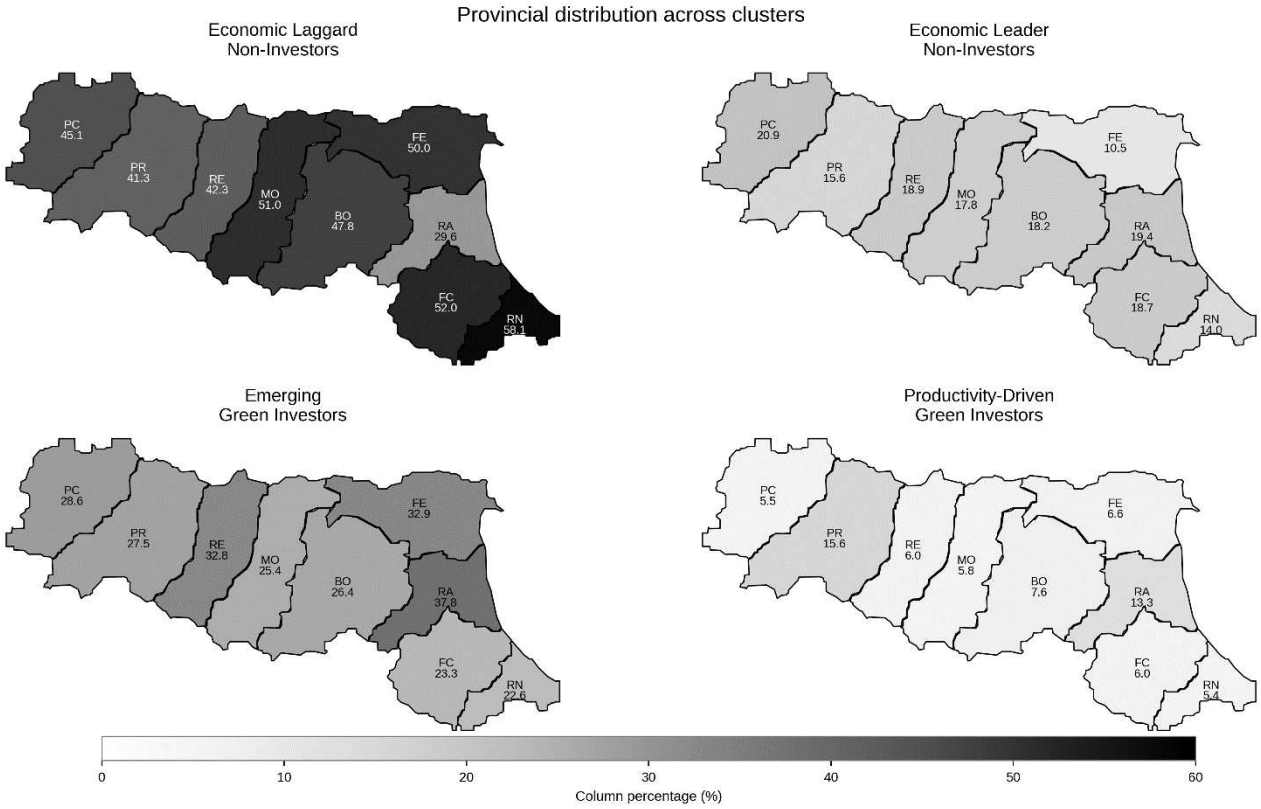


Construction



Transport





Source: Authors' own elaboration

Notes: The values reported within each size, sector and province dimensions indicate the column percentage of firms belonging to the corresponding cluster. PC = Piacenza; PR = Parma; RE = Reggio Emilia; MO = Modena; BO = Bologna; FE = Ferrara; RA = Ravenna; FC = Forlì-Cesena; RN = Rimini.

Cluster 1 *Economic Laggard Non-Investors* is the largest group in the sample, comprising 721 firms, or 46.9% of the total. It is the only cluster that records below-average values across all three economic dimensions used in the cluster analysis: profitability (-0.445), productivity (-0.219), and growth (-0.172). This weak economic profile is combined with the lowest overall propensity to undertake eco-innovation-related investments (-0.654) and below-average values across all environmental investment domains. The cluster is more prevalent among micro and small firms than among medium and large firms. Sectorally, it is particularly frequent in Transport and Construction, while it is less common in Agriculture. When eco-innovation-related investments activity is observed, it is mainly concentrated in Climate Mitigation and Circular Economy, whereas engagement in Climate Adaptation, Water Management, Pollution Prevention and Biodiversity remains marginal.

Cluster 2 *Economic Leader Non-Investors* includes 270 firms, corresponding to 17.6% of the sample. Its defining feature is the combination of strong prior economic performance and limited environmental investment engagement. Firms in this cluster display the highest profitability in the sample (1.300) and above-average growth (0.543), while productivity is only moderately above the sample mean (0.240). Despite this favourable economic position, the cluster records low values across all environmental investment variables and a negative overall investment propensity (-0.438). Compared with Cluster 1, investment activity is

somewhat more frequent, but it remains concentrated in the most common domains, namely Climate Mitigation and Circular Economy. Other investment areas remain limited. This profile suggests that favourable prior economic conditions seem to not automatically translate into broader engagement in eco-innovation-related investments.

Cluster 3 *Emerging Green Investors* comprises 427 firms, or 27.8% of the sample. Firms in this group show meaningful engagement in environmental investment, as reflected in a clearly positive investment propensity score (1.167). However, their economic profile does not indicate a strong prior advantage: profitability (-0.091), productivity (0.064), and growth (-0.085) are all close to the sample average. This cluster is therefore best interpreted as a group of emerging green investors: firms that undertake environmental investments despite not being clear economic leaders before the investment period. Their investment profile is highly concentrated in Climate Mitigation and Circular Economy, where adoption is widespread, while Pollution Prevention shows intermediate uptake. By contrast, Climate Adaptation, Water Management and Biodiversity remain relatively limited. Structurally, the cluster is more frequent among medium and large firms than among micro firms, suggesting that some minimum organisational or financial capacity may facilitate entry into eco-innovation investment.

Cluster 4 *Productivity-Driven Green Investors* is the smallest cluster, including 119 firms, or 7.7% of the sample. It is distinguished by the highest and most diversified environmental investment profile. The cluster records the strongest values for Climate Mitigation, Climate Adaptation, Water Management, Circular Economy, Pollution Prevention and Biodiversity, as well as a high overall investment propensity score (1.226). Economically, its most distinctive feature is productivity, which is substantially above the sample average (0.701). Profitability is close to the mean, while growth does not clearly distinguish this cluster from the lower-performing groups. This suggests that the most diversified environmental investment strategies are associated less with general economic leadership than with a specific productivity advantage. Structurally, Cluster 4 is much more frequent among large firms and much less frequent among micro firms. Sectorally, it appears particularly concentrated in Agriculture and in utilities/water-energy supply sectors.

The four-cluster solution reveals that firms differ in the way eco-innovation-related investments are combined with prior economic conditions. The taxonomy distinguishes between firms characterised by weak prior economic performance and low investment engagement (Cluster 1), firms that remain weakly engaged despite favourable prior economic conditions (Cluster 2), firms that undertake eco-innovation-related investments without a clear prior economic advantage (Cluster 3), and firms that combine intensive and diversified environmental investment with distinctly higher productivity (Cluster 4). Taken together, these four profiles show that the relationship between prior economic performance and eco-innovation-related investment is not reducible to a single linear trajectory. The contrast between Cluster 1 and Cluster 3 indicates that firms with relatively weak or non-leading prior economic profiles may follow divergent green investment paths. Similarly, the contrast between Cluster 2 and Cluster 4 shows that economically stronger firms may either remain weakly engaged or develop more advanced and diversified green investment strategies. As a result, firms do not simply

invest because they are economically stronger, nor do they necessarily remain excluded from eco-innovation-related investment because they are weaker. Rather, they combine economic conditions and environmental investment behaviour in heterogeneous ways.

4.2 External validation of the cluster taxonomy

The profiling presented in Section 4.1 is based on the variables used to construct the clusters, and the differences reported there are, to a large extent, definitional: a clustering algorithm is designed to maximise separation between groups on precisely those variables. A more stringent test of the taxonomy's validity is whether the four clusters also differ systematically on variables that played no role in the clustering procedure. If firms classified as more engaged in environmental investment also display distinct behaviour on unrelated dimensions, this indicates that the taxonomy captures a coherent orientation, rather than being an artefact of the clustering algorithm.

To this end, following the approach adopted in Marin et al. (2015), Table 3 reports cluster differences on seven outcome variables not included in the cluster analysis: awareness of the EU Taxonomy Regulation, activation of external sustainability-related consulting, use of environmental subsidies or incentives, adoption of product and process innovation introduced between 2019 and 2024, the presence of dedicated environmental staff, and exposure to the 2023 flood event as an exogenous shock unrelated to firms' investment strategies. Binary outcomes are tested using Pearson's χ^2 test of independence, complemented by Fisher's exact test given the relatively small cell counts for some outcomes (e.g., subsidy use); the continuous outcome is tested with a one-way ANOVA and, given the pronounced zero-inflation of the variable, with the non-parametric Kruskal-Wallis test as a robustness check.

Table 3. External profiling- cluster differences on outcome variables (not used in clustering)

Outcome variable (dichotomous)	*Economic Laggard Non-Investors* (N=721)	*Economic Leader Non-Investors* (N=270)	*Emerging Green Investors* (N=427)	*Productivity-driven Green Investors* (N=119)	χ^2 (df=3) Pearson	Fisher's exact p-value
Awareness of Taxonomy Regulation (852/2020)	18,6%	20,4%	42,9%	54,6%	126.76 (p<0.001)	<0.001
Activated sustainability consulting	9,3%	15,2%	30,0%	52,9%	165.99 (p<0.001)	<0.001
Used environmental subsidies	3,5%	3,0%	15,5%	19,3%	83.02 (p<0.001)	<0.001
Product Innovation (2019–2024)	26,4%	33,0%	42,4%	46,2%	40.35 (p<0.001)	<0.001
Process Innovation (2019–2024)	23,6%	29,6%	41,2%	56,3%	73.07 (p<0.001)	<0.001
Dedicated environmental staff	16,4%	19,0%	31,8%	48,7%	80.84 (p<0.001)	n/a
Shock exposure	7,1%	6,2%	8,8%	8,7%	1.67 (p=0.643)	0.627
Outcome variable (continuous)	*Economic Laggard*	*Economic Leader*	*Emerging*	*Productivity-driven*	ANOVA F / Kruskal-Wallis χ^2	Bartlett χ^2 (3)

	Non-Investors (N=721)	*Non-Investors* (N=270)	*Green Investors* (N=427)	*Green Investors* (N=119)		
Dedicated environmental staff (share of employees)	4,5%	2,7%	6,1%	8,4%	F=4.57** / KW χ^2=36.69 (66.25 w/ ties) ***	150.20***

Notes: *** p<0.001, ** p<0.05, * p<0.10. Binary outcomes tested with Pearson's χ^2 (df=3) and Fisher's exact test. The continuous outcomes are tested with one-way ANOVA (F) and, given its pronounced zero-inflation, with the non-parametric Kruskal-Wallis test (χ^2, with ties); Bartlett's $\chi^2(3)$ tests the underlying assumption of equal variances across clusters.

The results presented in Table 3 show that the four clusters differ systematically on outcome variables unrelated to the clustering procedure, providing evidence of external validity. For instance, awareness of the Taxonomy Regulation rises from 18.6% among Economic Laggard Non-Investors to 54.6% among Productivity-driven Green Investors, and a similar pattern holds for external consulting (9.3% to 52.9%) and subsidy use (3.5% to 19.3%). The only exception is shock exposure, which does not differ significantly across clusters, indicating that the taxonomy is not simply capturing differential exposure to the 2023 flood.

4.3 Robustness check: a regression-based approach

The differences reported in Table 3 are unconditional and may reflect differences in the structural composition of the clusters. In particular, investor clusters include larger shares of medium-sized and large firms, which are also more likely to possess specialised expertise, use external consulting, and access public support. We therefore examine whether the external characteristics documented in Table 3 remain associated with investment engagement after accounting for observable firm characteristics. This analysis also addresses the second objective of the paper by assessing whether other factors are associated with investment engagement beyond firms' prior economic conditions.

We estimate separate logit models for two pairs of clusters: Economic Laggard Non-Investors versus Emerging Green Investors (Clusters 1 and 3), and Economic Leader Non-Investors versus Productivity-Driven Green Investors (Clusters 2 and 4). These comparisons contrast investor and non-investor profiles with broadly similar, although not identical, prior economic conditions. Within each pair, the dependent variable equals one for membership in the investor cluster and zero for membership in the corresponding non-investor cluster. The pairwise specification allows us to examine which characteristics distinguish firms that display different investment engagement despite facing broadly comparable initial economic conditions.

For each comparison, we estimate two specifications. The baseline model includes firm size, sector, province, and managerial characteristics. The full model adds the external characteristics considered in Table 3. The comparison between the two specifications shows how the associations with structural characteristics change when these additional factors are introduced and whether the latter are systematically associated with membership in the investor cluster. Table 4 reports average marginal effects based on logit estimates with robust standard errors. The corresponding coefficients are reported in Appendix Table A4.

Table 4. Average marginal effects (logit): Cluster 1 Vs Cluster 3 and Cluster 2 Vs Cluster 4

	Weak economic performance: *Economic Laggard* *Non-Investors* Vs *Emerging Green Investors*		**Strong economic performance:** *Economic Leader* *Non-Investors* Vs *Productivity-driven Green Investors*	
	Baseline	**Full model**	**Baseline**	**Full model**
Small	0.0719**	0.0091	0.1090**	0.0345
	(0.0312)	(0.0328)	(0.0471)	(0.0527)
Medium	0.1816***	0.0077	0.3100***	0.1295*
	(0.0510)	(0.0504)	(0.0698)	(0.0724)
Large	0.2425***	0.0470	0.4676***	0.2384**
	(0.0804)	(0.0919)	(0.1192)	(0.1193)
Manufacturing	0.2274**	0.1444	-0.4821***	-0.5217***
	(0.0927)	(0.1475)	(0.0928)	(0.0877)
Utilities/water-energy supply	0.2112	0.1423	-0.0314	-0.0597
	(0.1427)	(0.1772)	(0.1436)	(0.1368)
Construction	0.1972**	0.1459	-0.5503***	-0.4883***
	(0.0963)	(0.1489)	(0.1019)	(0.1007)
Transport	0.1533	0.1181	-0.5831***	-0.5950***
	(0.1025)	(0.1518)	(0.1204)	(0.1184)
Ferrara	0.0666	0.0108	-0.0547	0.0549
	(0.0684)	(0.0736)	(0.1211)	(0.1181)
Forlì-Cesena	-0.0504	-0.1031*	-0.0572	0.0534
	(0.0532)	(0.0549)	(0.0783)	(0.0857)
Modena	-0.0268	-0.0736*	-0.0550	-0.0169
	(0.0428)	(0.0432)	(0.0653)	(0.0630)
Parma	0.0408	-0.0354	0.1258	0.1238
	(0.0557)	(0.0549)	(0.0767)	(0.0774)
Piacenza	0.0353	0.0485	-0.0787	-0.0252
	(0.0669)	(0.0695)	(0.0871)	(0.0586)
Ravenna	0.2093***	0.0806	-0.0717	-0.0460
	(0.0695)	(0.0711)	(0.0830)	(0.1099)
Reggio Emilia	0.0765	0.0369	-0.0636	-0.0246
	(0.0500)	(0.0514)	(0.0688)	(0.0648)
Rimini	-0.0488	-0.0356	0.0017	0.0442
	(0.0639)	(0.0663)	(0.1293)	(0.1020)
Manager's age	-0.0012	-0.0008	-0.0002	-0.0007
	(0.0014)	(0.0015)	(0.0020)	(0.0021)
Manager's Education	0.0134	0.0109	0.0163	0.0007
	(0.0151)	(0.0158)	(0.0221)	(0.0236)
Knowledge		0.1865***		0.0878**
		(0.0295)		(0.0434)
Consulting		0.1779***		0.2029***
		(0.0381)		(0.0390)
Dedicated Staff		-0.0174		0.2348
		(0.0966)		(0.1557)
Environmental subsidies		0.2810***		0.1551*
		(0.0550)		(0.0848)
Product innovation		0.0420		0.0245
		(0.0346)		(0.0472)
Process innovation		0.0852**		0.1419***
		(0.0346)		(0.0486)

	Weak economic performance: *Economic Laggard* *Non-Investors* Vs *Emerging Green Investors*		**Strong economic performance:** *Economic Leader* *Non-Investors* Vs *Productivity-driven Green Investors*	
	Baseline	**Full model**	**Baseline**	**Full model**
Shock exposure		0.0320 (0.0597)		-0.1335 (0.1097)
N. Obs.	1140	955	386	325
Pseudo R-squared	0,0337	0,1416	0,2097	0,3671
Chi-squared	48,83	133,33	86,96	97,59

Notes: Reported are Average Marginal Effects. Robust standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01. Reference categories: firm size = Micro; sector = Agriculture; province = Bologna.

Table 4 reports the average marginal effects from the pairwise logit models. Among firms with relatively weak prior economic performance, the baseline estimates show a clear size effect. Relative to micro firms, small firms are 7.2 percentage points more likely to belong to the Emerging Green Investors cluster, medium-sized firms 18.2 percentage points more likely, and large firms 24.3 percentage points more likely. These differences become small and statistically insignificant in the full specification.

The full model instead points to a consistent role for regulatory knowledge, external expertise, public support, and process innovation. Awareness of the EU Taxonomy Regulation is associated with an 18.7 percentage point increase in the probability of belonging to the investor cluster, while the corresponding effect for external consulting is 17.8 percentage points. Environmental subsidies have the largest marginal effect, at 28.1 percentage points, and process innovation is associated with an increase of 8.5 percentage points. Dedicated environmental staff, product innovation, and exposure to the 2023 flood are not statistically significant.

The comparison between the two economically stronger profiles yields a similar pattern. In the baseline model, the probability of belonging to the Productivity-Driven Green Investors cluster increases by 10.9 percentage points for small firms, 31.0 percentage points for medium-sized firms, and 46.8 percentage points for large firms, relative to micro firms. These estimates decline in the full specification. The effect for small firms becomes statistically insignificant, while those for medium-sized and large firms remain positive, although substantially smaller.

Regulatory knowledge, external consulting, environmental subsidies, and process innovation are again positively associated with membership in the investor cluster. External consulting has the largest marginal effect, at 20.3 percentage points, followed by environmental subsidies at 15.5 percentage points and process innovation at 14.2 percentage points. The estimate for environmental subsidies is significant only at the 10 percent level. Regulatory knowledge is associated with an 8.8 percentage point increase. Sectoral differences also remain substantial: relative to agricultural firms, firms in manufacturing, construction, and transport are between 48.8 and 59.5 percentage points less likely to belong to the Productivity-Driven Green Investors cluster.

Overall, the results show that structural characteristics alone do not account for the distinction between investor and non-investor profiles. Firm size is strongly associated with investment engagement in the baseline models,

but much of this association is attenuated once the additional firm-level characteristics are introduced. Regulatory knowledge, external consulting, environmental subsidies, and process innovation emerge as the most consistent correlates of investor-cluster membership across the two comparisons. These findings suggest that firms' engagement in eco-innovation-related investment is associated not only with their economic and organisational capacity, but also with access to information, external expertise, public support, and complementary innovation activities.

5. Conclusions

The green transition requires firms to commit resources to investments whose costs are immediate but whose returns are often uncertain. Prior economic performance may therefore matter for firms' ability to undertake eco-innovation-related investments. Better performing firms have greater internal resources and are generally better positioned to absorb the associated costs and risks. At the same time, environmental investment may provide firms facing less favourable conditions with opportunities to improve resource efficiency, reduce costs, and reposition themselves strategically. The relationship between prior economic performance and environmental investment is therefore unlikely to be uniform across firms. This heterogeneity has important policy implications. If firms with weaker economic performance are less able to undertake the investments required by the green transition, environmental policy may widen existing differences between firms. Identifying which firms face the greatest constraints, and whether these constraints reflect limited economic capacity or other factors, is therefore important for targeting support and preventing weaker firms from falling further behind.

This paper examines this relationship using an original dataset of 1,537 firms operating in Emilia-Romagna. We combine information on firms' economic performance before the investment period with survey data covering investments across six environmental areas. In line with the evolutionary tradition, rather than imposing a predetermined relationship between these dimensions, we use cluster analysis to identify the configurations that emerge from the data. We then compare investor and non-investor profiles with broadly comparable prior economic conditions to examine which other firm-level characteristics are associated with differences in investment engagement.

The analysis identifies four distinct profiles. Economic Laggard Non-Investors, which represent 46.9% of the sample, combine weak prior economic performance with poor environmental investment. Economic Leader Non-Investors account for 17.6% of the sample and show that favourable profitability and growth do not necessarily translate into environmental investment. Emerging Green Investors, representing 27.8% of the sample, undertake substantial eco-innovation-related investments despite lacking a clear prior economic advantage. Finally, Productivity-Driven Green Investors account for 7.7% of the sample and combine high and diversified investment engagement with stronger prior productivity.

These profiles document substantial heterogeneity in the relationship between economic performance and environmental investment. Firms without a clear prior economic advantage may nevertheless invest, while

firms with favourable economic conditions may remain weakly engaged. Prior economic performance therefore matters, but its different dimensions do not correspond uniformly to firms' environmental investment choices.

The regression-based robustness check provides additional support for this interpretation. Across both comparisons, regulatory knowledge, external consulting, environmental subsidies, and process innovation are systematically associated with membership in the investor clusters after controlling for observable firm characteristics. These estimates represent conditional correlations rather than causal effects. Nevertheless, they indicate that economic and organisational capacity alone does not fully account for differences in investment engagement. This interpretation is consistent with firm-level evidence on the roles of environmental regulation, external advice and public funding in eco-innovation and resource-efficiency practices (Bodas-Freitas and Corrocher, 2019; Cecere et al., 2020; Aristei and Gallo, 2021).

The findings have two main implications for policy. First, policies based exclusively on firms' financial capacity may fail to account for important differences in environmental investment. Some economically stronger firms remain weakly engaged, indicating that the availability of internal resources does not automatically translate into environmental investment. At the same time, some firms invest despite lacking a clear prior economic advantage. Financial conditions alone are therefore insufficient to distinguish firms that invest from those that do not.

Second, and in support of the above, the regression results show that regulatory knowledge, external consulting, environmental subsidies, and process innovation distinguish investors from non-investors even among firms with broadly comparable prior economic conditions. The associations with regulatory knowledge and external consulting indicate that the implementation of environmental policy depends not only on the stringency of regulation but also on firms' ability to understand and respond to it. Measures that reduce information costs and facilitate access to specialised expertise may be therefore particularly important. In addition, the positive association between environmental subsidies and investor-cluster membership is also consistent with a role for public support in reducing the costs and risks of environmental investment. These results, nonetheless, identify potential areas for policy intervention, although the cross-sectional nature of the analysis does not allow us to establish causal effects.

Several limitations qualify these findings. The survey records whether firms undertook specific environmental investments, but not the resulting innovation outcomes. Our measures therefore capture engagement in eco-innovation-related investment rather than realised eco-innovation. Moreover, although economic performance is measured before the investment period, the timing of individual investments is not observed, and several firm-level covariates are self-reported and measured over an overlapping period. The regression results should consequently be interpreted as conditional correlations rather than causal effects. Finally, the analysis is limited to firms in Emilia-Romagna. Whether the identified profiles extend to other regions and institutional settings remains an open empirical question.

Declarations

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Clinical trial number

Not applicable.

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Appendix

A1. Relevant questions in the ECOSISTER survey

E4. Type of past interventions: specify whether the firm has invested over the past five years in actions associated with the following sustainability areas envisaged by the Regulation. (One Yes/No answer for each item, with the option to indicate "Not relevant to the firm's activity".)

Sustainability area	The firm invested in the last five years (2019–2023)
Area 1: Climate change mitigation	
1. Production and distribution of renewable energy	□ Yes □ No □ Not relevant to the firm's activity
2. Efficiency improvement of equipment, machinery, and means of transport	□ Yes □ No □ Not relevant to the firm's activity
3. Use of renewable energy in the production process	□ Yes □ No □ Not relevant to the firm's activity
4. Efficiency improvement in water use in the production process	□ Yes □ No □ Not relevant to the firm's activity
5. Efficiency improvement in the use of electricity, from any source, in the production process	□ Yes □ No □ Not relevant to the firm's activity
6. Adoption of low-carbon technologies for transport and mobility	□ Yes □ No □ Not relevant to the firm's activity
7. Adoption of models and technologies for CO_2 absorption	□ Yes □ No □ Not relevant to the firm's activity
Area 2: Climate change adaptation	
8. Investments in green infrastructure to offset CO_2 production, such as urban green spaces and reforestation	□ Yes □ No □ Not relevant to the firm's activity
9. Investments in blue infrastructure to offset CO_2 production, such as riverbed restoration and canalisation works	□ Yes □ No □ Not relevant to the firm's activity
10. Investments in resilient agri-food supply chains	□ Yes □ No □ Not relevant to the firm's activity
Area 3: Sustainable use and protection of water and marine resources	
11. Water recovery/protection	□ Yes □ No □ Not relevant to the firm's activity
12. Recovery of wastewater, both industrial and urban	□ Yes □ No □ Not relevant to the firm's activity
13. Efficient planning and management of water resources, including surface, groundwater, and/or marine water	□ Yes □ No □ Not relevant to the firm's activity
Area 4: Transition to a circular economy	
14. Reduction of unnecessary materials and resources in product/service design, such as avoiding packaging where possible, avoiding shipping film, and avoiding plastic carrier bags	□ Yes □ No □ Not relevant to the firm's activity
15. Use of regenerative/biodegradable materials in product/service offerings	□ Yes □ No □ Not relevant to the firm's activity
16. Reuse and recycling of the firm's own waste materials within the company, such as chemicals, oils, packaging, plastics, and any other non-biodegradable materials	□ Yes □ No □ Not relevant to the firm's activity

involved, or use of raw materials and/or components from other companies' recycling processes	
17. Adoption of processes for recovering products and items no longer used by customers	□ Yes □ No □ Not relevant to the firm's activity
18. Use of local suppliers of goods and services, and other measures to reduce transport-related impacts, such as full-load transport and sustainable employee mobility	□ Yes □ No □ Not relevant to the firm's activity
19. Repair and maintenance of defective products and materials so that they can be used for their original function or for a different function	□ Yes □ No □ Not relevant to the firm's activity
20. Provision to customers of documentation, tools, and support to extend product lifetimes, such as customer maintenance and repair, and warranty extensions	□ Yes □ No □ Not relevant to the firm's activity
21. Adoption of internal training plans for staff on the circular economy	□ Yes □ No □ Not relevant to the firm's activity
22. Use of documented social and/or environmental impact assessments according to nationally or internationally recognised standards	□ Yes □ No □ Not relevant to the firm's activity
23. Recognition of internal awards and/or incentives linked to circular economy objectives	□ Yes □ No □ Not relevant to the firm's activity
24. Reduction of waste generated per unit of output, including through material incineration with energy recovery	□ Yes □ No □ Not relevant to the firm's activity
25. Transfer of the firm's waste to other companies that use it in their own production cycle	□ Yes □ No □ Not relevant to the firm's activity
Area 5: Pollution prevention and reduction	
26. Reduction of direct emissions of greenhouse gases, such as carbon dioxide, methane, and nitrous oxide, or other pollutants, such as PM10, sulphur dioxide, and nitrogen oxides, into air, water, and soil	□ Yes □ No □ Not relevant to the firm's activity
27. Elimination of indirect pollution	□ Yes □ No □ Not relevant to the firm's activity
28. Remediation of the effects of pollution produced in the past	□ Yes □ No □ Not relevant to the firm's activity
Area 6: Protection and restoration of biodiversity and ecosystems	
29. Conservation/improvement of the condition of semi-natural or natural ecosystems	□ Yes □ No □ Not relevant to the firm's activity
30. Maintaining sustainable use / reducing pressure and mitigating impacts on managed ecosystems, that is, ecosystems regulated by humans	□ Yes □ No □ Not relevant to the firm's activity

A2. Principal Component analysis

A2.1 Variables selection

The PCA was used to reduce a broad set of economic and financial indicators into a smaller number of synthetic dimensions capturing firms' economic conditions prior to the investment's decision.

We initially selected 16 indicators from the AIDA database related to the period 2015-2018, namely ROA, ROI, EBITDA, ROS, Debt/Equity, Debt/EBITDA, interest coverage, liquidity ratio, revenues per employee, value added per employee, labour cost per employee, employee productivity, CAGR of revenues, CAGR of value added, CAGR of employees, CAGR of value added per employee. For variables observed annually, we computed the average over 2015–2018. For growth variables, we computed the compound annual growth rate over 2015–2018.

Before running the PCA, we inspected missing values, outliers, descriptive statistics and correlations. This led us to exclude ROI, Debt/Equity and Debt/Ebitda due to a high number of missing values and extreme observations.

The thirteen variables were subsequently winsorized at the 1st and 99th percentiles. This reduced the influence of extreme observations while preserving the full sample size. After winsorization, all variables were standardized into z-scores.

A2.2 PCA estimation

The PCA was then estimated on the 13 standardized and winsorized variables. Although the Kaiser criterion suggested retaining five components (eigenvalues above one), the first three components already explained approximately 61.7% of the total variance, while the fourth and fifth components added only 8.48% and 8.16%, respectively. For this reason, we selected three components based on explained variance above 60%; interpretability of the rotated loadings; parsimony for subsequent cluster analysis.

Table A1. Principal component analysis: eigenvalues and cumulative explained variance

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	3,25922	0,73700	0,2507	0,2507
Comp2	2,52222	0,27863	0,1940	0,4447
Comp3	2,24359	1,14068	0,1726	0,6173
Comp4	1,10291	0,04147	0,0848	0,7021
Comp5	1,06144	0,17788	0,0816	0,7838
Comp6	0,88356	0,37569	0,0680	0,8518
Comp7	0,50787	0,01716	0,0391	0,8908
Comp8	0,49071	0,15481	0,0377	0,9286
Comp9	0,33590	0,00516	0,0258	0,9544
Comp10	0,33074	0,21774	0,0254	0,9799
Comp11	0,11300	0,02721	0,0087	0,9886
Comp12	0,08579	0,02275	0,0066	0,9952
Comp13	0,06304	-	0,0048	1,0000

We applied a varimax rotation to improve interpretability. Loadings above 0.35 in absolute value were used to interpret the components.

Table A2. Varimax-rotated component loadings

Variable	Profitability	Growth	Productivity	Unexplained
z_CAGR of revenues_w		0.5571		0.2760
z_Liquidity ratio_w				0.6829
z_Interest coverage_w				0.6128
z_EBITDA_w	0.4762			0.2794
z_ROA_w	0.4843			0.2452
z_ROS_w	0.5138			0.1553

z_CAGR of employees_w	0.4232		0.5742
z_Revenues per employees_w		0.6048	0.0880
z_Value added per employee_ w		0.4956	0.1755
z_CAGR of value added per employee_w	0.3705		0.6792
z_Labour cost_w		0.3588	0.5650
z_Employee productivity_w		0.4952	0.3655
z_CAGR of value added_w	0.5542		0.2760

Finally, we predicted component scores for the three retained dimensions: *Profitability*, *Productivity* and *Growth*. These scores were then standardized again before being used in the cluster analysis.

A3. Cluster analysis: choice of the optimal number of clusters

In the absence of a conclusive test for determining the appropriate number of clusters to retain, several rules of thumb can be used, based on statistical criteria such as the Pseudo T-squared statistic, the Je(2)/Je(1) statistic, and the Calinski-Harabasz pseudo-F statistic. These indicators assess the extent to which alternative cluster solutions are distinct from one another (Marin and Vona, 2019). Clusters should indeed exhibit high heterogeneity between groups while maintaining similarity among observations within the same group.

The number of clusters was selected by combining the Duda-Hart and Calinski-Harabasz stopping rules. According to the Duda-Hart criterion, the preferred solution should be associated with a large and locally maximal value of the Je(2)/Je(1) statistic and a locally low value of the pseudo T-squared statistic. The four-cluster solution shows the highest Je(2)/Je(1) value among the tested partitions and a very low pseudo T-squared value. Although the pseudo T-squared statistic reaches its minimum at five clusters, the corresponding Je(2)/Je(1) value drops sharply, suggesting a less stable partition. The Calinski-Harabasz pseudo-F statistic also reaches its maximum at four clusters. Overall, the stopping rules support the selection of a four-cluster solution, which was retained for the subsequent k-means clustering.

Table A3. Stopping-rule statistics for the hierarchical cluster solution

Number of clusters	Je(2)/Je(1)	Pseudo T-squared	Calinski/Harabasz pseudo-F
3	0.8928	182.61	69.04
4	**0.9430**	2.48	**111.91**
5	0.6000	**2.00**	85.39
6	0.8747	211.71	69.22
7	0.6117	4.44	99.10

Visual inspection of the dendrogram supports the four-cluster solution. A cut at the intermediate dissimilarity level separates the observations into four main branches, suggesting that the four-cluster partition captures the main structure of the data before larger and more heterogeneous groups are merged.

Figure A1. Average-linkage dendrogram for the cluster solution

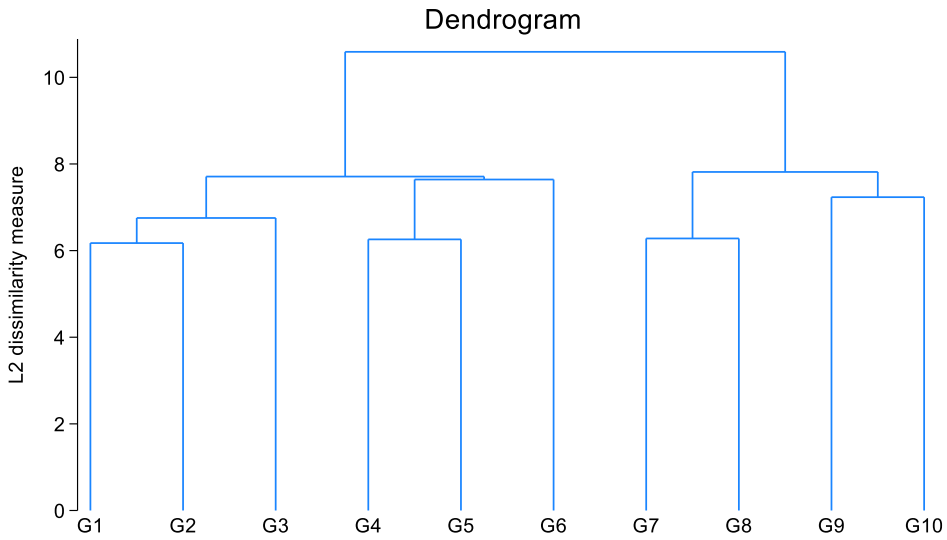


Table A.4 Logit estimates: Cluster 1 versus Cluster 3 and Cluster 2 versus Cluster 4

	Weak economic performance: *Economic Laggard Non-Investors vs Emerging Green Investors*		**Strong economic performance**: *Economic Leader Non-Investors vs Productivity-driven Green Investors*	
Variables	**Baseline**	**Full model**	**Baseline**	**Full model**
Small	0.3281**	0.0476	0.7856**	0.2865
	(0.1448)	(0.1728)	(0.3582)	(0.4419)
Medium	0.7884***	0.0380	1.8186***	0.9739*
	(0.2179)	(0.2646)	(0.4071)	(0.5378)
Large	1.0386***	0.2389	2.5454***	1.6628**
	(0.3377)	(0.4627)	(0.6164)	(0.7528)
Manufacturing	1.2407*	0.8632	−2.4218***	−3.3457***
	(0.6970)	(1.0375)	(0.5617)	(0.7030)
Utilities/water-energy supply	1.1692	0.8572	−0.1779	−0.3997
	(0.8476)	(1.1560)	(0.8098)	(0.9223)
Construction	1.1062	0.8703	−2.8669***	−3.0802***
	(0.7082)	(1.0426)	(0.6301)	(0.7341)
Transport	0.9012	0.7218	−3.1190***	−4.0208***
	(0.7298)	(1.0542)	(0.8554)	(1.1336)
Ferrara	0.2887	0.0547	−0.3460	0.4300
	(0.2924)	(0.3706)	(0.8018)	(0.8903)
Forlì-Cesena	−0.2344	−0.5670*	−0.3627	0.4183
	(0.2509)	(0.3152)	(0.5117)	(0.6538)
Modena	−0.1222	−0.3932*	−0.3476	−0.1423
	(0.1952)	(0.2328)	(0.4184)	(0.5341)
Parma	0.1791	−0.1852	0.6917*	0.9192*
	(0.2427)	(0.2886)	(0.4143)	(0.5436)
Piacenza	0.1550	0.2426	−0.5112	−0.2203
	(0.2913)	(0.3414)	(0.5969)	(0.5031)
Ravenna	0.8796***	0.3962	−0.4621	−0.3988
	(0.2948)	(0.3424)	(0.5617)	(1.0074)
Reggio Emilia	0.3303	0.1846	−0.4060	−0.2089
	(0.2155)	(0.2554)	(0.4486)	(0.5545)

Rimini	−0.2268	−0.1824	0.0099	0.3492
	(0.3031)	(0.3503)	(0.7727)	(0.7835)
Manager's age	−0.0054	−0.0042	−0.0016	−0.0056
	(0.0064)	(0.0079)	(0.0125)	(0.0170)
Manager's education	0.0600	0.0569	0.1040	0.0059
	(0.0676)	(0.0832)	(0.1404)	(0.1909)
Knowledge		0.9831***		0.7114**
		(0.1664)		(0.3563)
Consulting		0.9397***		1.6443***
		(0.2082)		(0.3641)
Dedicated staff		−0.0915		1.9021
		(0.5091)		(1.2635)
Environmental subsidies		1.4811***		1.2529*
		(0.3034)		(0.6998)
Product innovation		0.2218		0.1977
		(0.1831)		(0.3822)
Process innovation		0.4487**		1.1501***
		(0.1843)		(0.4225)
Shock exposure		0.1696		−1.0800
		(0.3143)		(0.8953)
Constant	−1.9033**	−2.0560*	0.4207	0.3434
	(0.8399)	(1.1710)	(1.0414)	(1.4268)
N. Obs.	1,140	955	386	325
Pseudo R-squared	0.0337	0.1416	0.2097	0.3672
Chi-squared	48.8278	133.3391	86.9564	97.5624