# Environmental degradation and firm failure: pollution umbrella effect in Spain

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**Keyworks:** *firm failure, spatial probit, groundwater pollution, ecosystem services*

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## Abstract

Groundwater pollution is a growing hazard to the correct functioning of social-ecological and economic systems. This study examines the impact of groundwater pollution on firm performance in an environmentally stressed area in SE Spain. This relationship has been previously analysed in environmental economics and financial studies from a variety of theoretical perspectives. Although the most recent studies find a negative impact of local environmental pollution on firm performance, it is still unclear how such a measure of environmental regulation is calculated. In this sense, this paper uses the last assessment of groundwater pollution, under the specifications of the EU Nitrates Directive 91/676/CEE, to test whether the absence of effective regulation against pollution, proxied by the firms' exposure to high levels of pollution, is affecting their probability of failure. To identify the direction and quantify the effect, we use firm-level panel data from the SABI database for a five-year period. Then the existence of a spatial contagion effect among close firms is evaluated through a spatial econometric model. Our conclusions show that exposure to environmental pollution is more detrimental for firms' survival than firms' size, age, and profitability ratios like ROA and ROE, and this effect is bigger for service sector businesses. Finally, we find no evidence that firms from any economic sector gain from the absence of effective regulation against nitrate pollution. Therefore, this paper empirically demonstrates the existence of a significant environmental-financial nexus and gives strong support to a stricter application of EU Directives against pollution.

## 1. Introduction

Environmental pollution and climate change are increasingly recognized as systemic risks to financial and macroeconomic stability (IMFs; IPCC, 2023; EC, 2020). In this context, a central question emerges: *to what extent does environmental status shape economic activity and firm-level outcomes?* While this issue has received growing attention in both environmental and financial economics, the underlying mechanisms linking environmental degradation to firm performance remain insufficiently understood (Migliorelli, 2023).

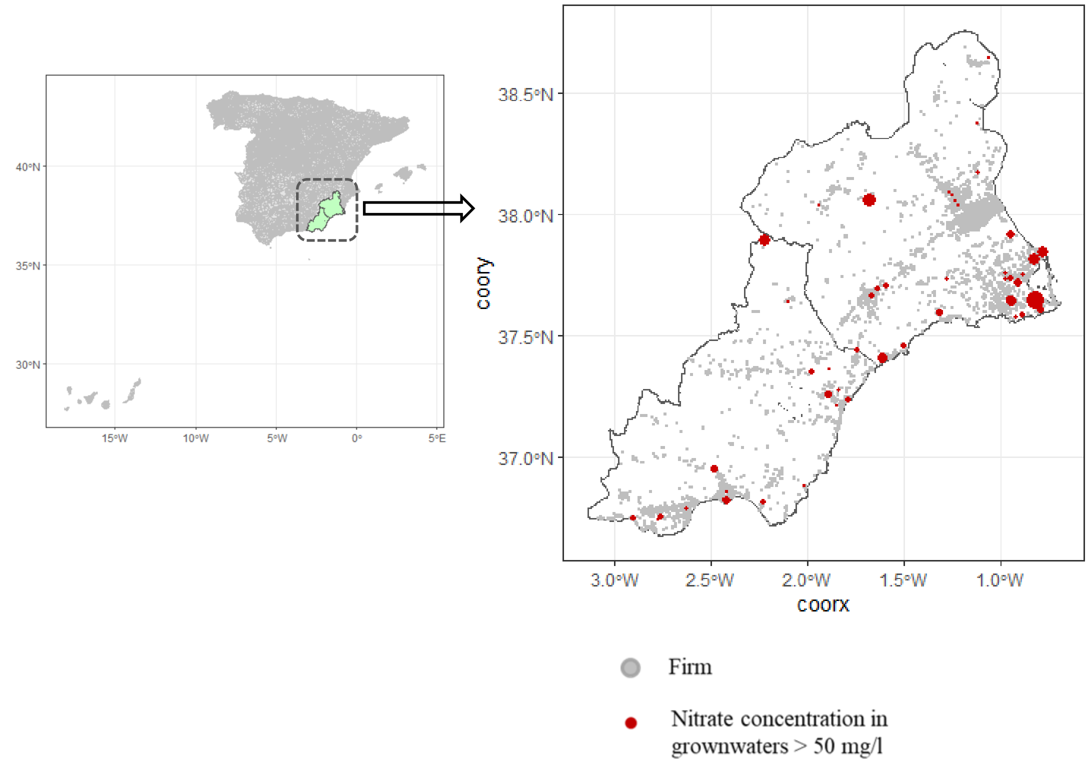
Nitrate pollution represents one of the most pressing environmental challenges affecting aquatic and terrestrial ecosystems worldwide, as the safe boundary for anthropogenic nitrogen fixation has been transgressed in several regions (Bijay-Singh and Craswell, 2021; Sakschewski et al 2025). Nitrate pollution is driven by both cropland expansion and higher nitrogen use rates -the result of a growing demand for agricultural productivity (Sakschewski et al 2025). In regions such as Mediterranean Spain, high fertilizer use has led to widespread accumulation of nitrogen in surface water and groundwater bodies (Omondi Oduor et al., 2023; de Paz and Ramos, 2002). As a result, approximately 30% of Spanish aquifers are currently classified as heavily polluted by nitrates (Pérez-Martín et al., 2024). Such persistent environmental stress undermines the resilience of the ecosystems and disrupts the provision of essential ecosystem services. Ecosystem services—ranging from clean water supply and food production to cultural and aesthetic benefits, pollution regulation, and climate mitigation—constitute a fundamental pillar of the ecological-economic system (Costanza et al., 1997; Winn and Pogutz, 2013). Disruptions in these services can translate into tangible economic losses (Costanza et al., 2014; Polasky and Daily, 2021). For instance, harmful algal blooms associated with water pollution have been shown to reduce income per capita in coastal areas (Aparicio et al., 2024). These findings suggest that environmental degradation is not merely an ecological concern but also a potential driver of economic and financial instability.

From a firm-level perspective, financial performance is often evaluated through the probability of business failure. A well-established determinant of firm survival is geographical location, including proximity to infrastructure, industrial clusters, and successful firms (Maté-Sánchez-Val et al., 2018). More recently, evidence has shown that proximity to environmental degradation—such as marine pollution—negatively affects firm survival (Maté-Sánchez-Val and Aparicio-Serrano, 2023). Building on this literature, this paper investigates the environmental-financial nexus from a geographical perspective, emphasizing the role of localized environmental conditions in shaping firm outcomes.

Our theoretical framework draws on Pigou (1920), who highlights how negative externalities generate market failures. When firms internalize only private production costs while externalizing environmental damages, pollution-intensive goods are overproduced. In intensive agricultural systems, these externalities often materialize as nitrate pollution in surface and groundwater bodies (Abascal et al., 2022) and an overall reduction of the ecosystem services provided and their resilience, as they are exploited beyond their regenerative capacity (Castro et al., 2018b; Quintas-Soriano et al., 2018; Winn and Pogutz, 2013). Under such conditions, market prices fail to reflect the true social-ecological cost of production, and part of the economic system absorbs these external costs, potentially leading to reduced firm performance, financial distress, and ultimately firm failure. We argue that this mechanism may be particularly relevant for firms in the service and tourism sectors, which are highly dependent on environmental quality. Empirical evidence supports this view, showing that environmental degradation leads to significant revenue losses in tourism-related activities, both through ecosystem deterioration (Lopes Diniz et al., 2026) and atmospheric pollution (Hao et al., 2021).

To empirically test this hypothesis, we focus on the semi-arid region of southeast Mediterranean Spain, specifically the provinces of Murcia and Almería (Fig. 1). This region is one of the main suppliers of horticultural products to the European Union, accounting for nearly 40% of Spanish fruit and vegetable exports (Jiménez-Aceituno et al., 2025). Since the 1980s, agricultural production in this region has intensified significantly, shifting from rain-fed systems to intensive irrigated agriculture sustained by underground water and water transfers. An example of this growth is that Almeria´s greenhouse-based system is internationally known as the Sea of Plastic (Sánchez-Picón et al., 2011). This transformation has enabled sustained production despite water scarcity, but it has also generated substantial negative socio-ecological externalities, including aquifer overexploitation, biodiversity loss, and ecosystem degradation (Jiménez-Aceituno et al., 2025, Castro et al., 2018a; Quintas-Soriano et al., 2018).

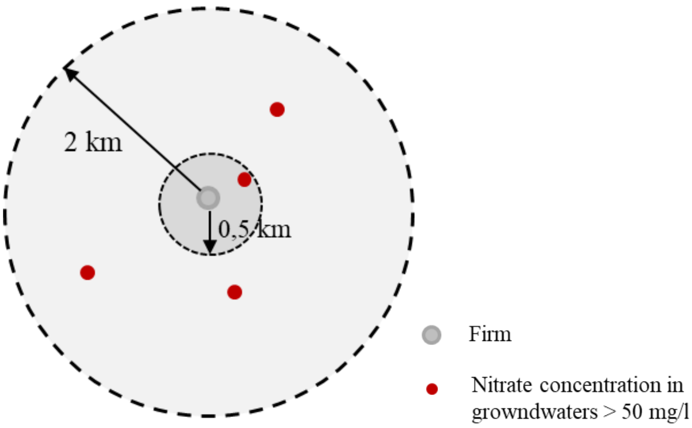
Figure 1. Firms' location and nitrates pollution in groundwater in Murcia and Almería provinces (SE Spain)




Source: Authors' own elaboration using RStudio based on information from MITECO (2025) and SABI (2025) databases.

Thus, this region provides an ideal setting due to its intensive agricultural activity and high levels of nitrate pollution. We examine whether firms' exposure to groundwater nitrate pollution affects financial performance. We conceptualize this relationship as the *pollution umbrella effect*, a spatial phenomenon whereby the impact of environmental degradation diminishes with distance from pollution sources. This effect is operationalized through a concentric ring methodology (Fig. 2), previously applied in financial geography to capture spatial density and sectoral specialization as determinants of firm failure (Maté-Sánchez-Val and Martínez-Victoria, 2025).

Figure 2. Graphical representation of the *pollution umbrella effect.*



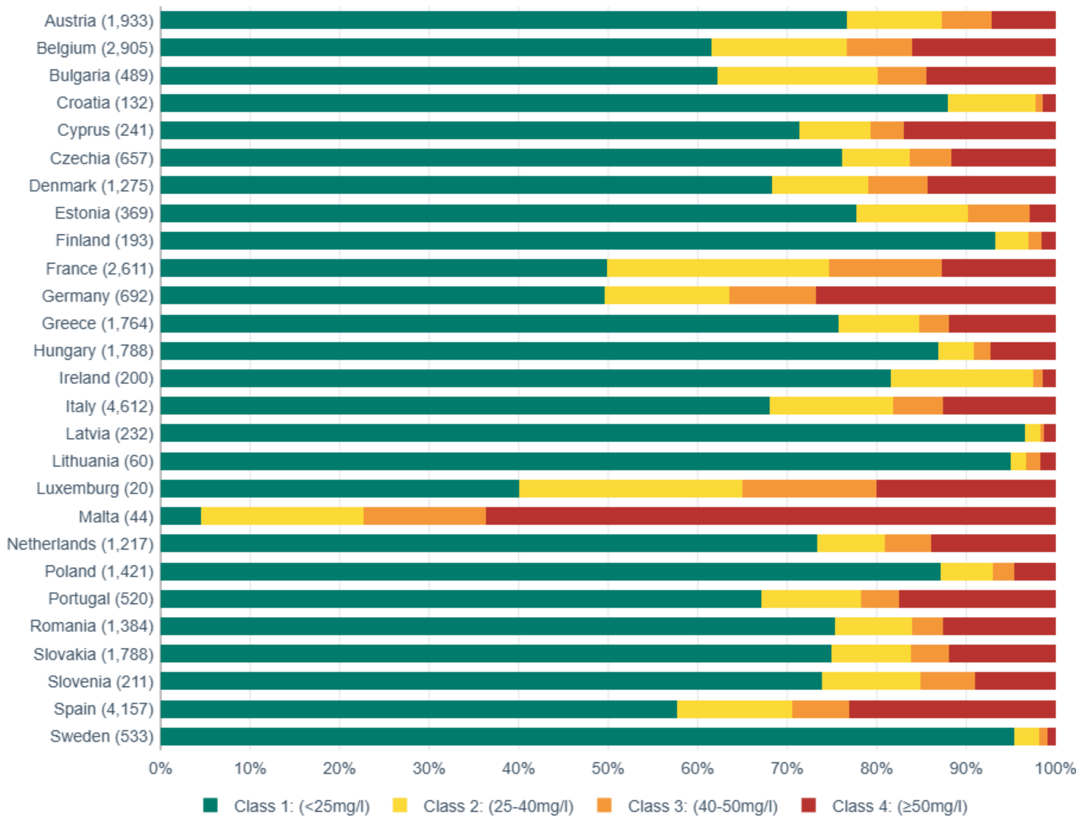

Source: Authors' own elaboration.

To assess the impact of environmental degradation on firm survival, we use data from the EU Nitrates Directive assessment of Spanish groundwaters for the period 2016–2019 (the last available). This Directive aims to reduce water pollution from agricultural nitrates, requiring Member States to monitor and classify water bodies that exceed the threshold of 50 mg/L $NO_3$. Currently, around 23% of groundwater bodies in Spain fail to meet these standards (Fig. 3), with significantly higher concentrations observed in the intensive agricultural regions of Murcia and Almería. Average nitrate concentrations in polluted areas reach 143.3 mg/L in these provinces, compared to 108.4 mg/L at the national level.

This study aims to quantify the extent to which environmental degradation acts as a determinant of firm failure in such a highly stressed ecological context. We argue that the degradation of common-pool resources, such as water and soil, should be understood not only as an environmental issue but also as a direct and measurable driver of firm mortality. In doing so, we challenge the neoclassical view that environmental regulation primarily imposes costs on firms, instead emphasizing the economic risks associated with insufficient environmental protection.

Although the relationship between nutrient pollution and ecosystem status has been extensively studied in biophysical research (Poikane et al., 2022; Grohmann & Feindt, 2023), the economic transmission mechanism linking pollution to firm failure remains underexplored. Our study contributes to this gap. First, it tests the hypothesis that environmental pollution increases the probability of firm failure for companies located near polluted areas. Second, given the dependence of service-sector firms on ecosystem services (Winn and Pogutz, 2013), our study tests the hypothesis that the negative impact of pollution is stronger in this sector.

Figure 3. Nitrates in groundwaters from the last assessment 2016-2019 according to the Nitrates Directive 91/676/CEE




Source: European Environment Agency (EEA) 2025.

Finally, building on evidence of spatial dependence in firm failure (Maté-Sánchez-Val et al., 2018; Maté-Sánchez-Val and Aparicio-Serrano, 2023), we seek to demonstrate that firm failure exhibits spatial clustering, namely, that the probability of failure increases when neighboring firms also fail. Overall, this paper contributes new empirical evidence to the debate on the role of environmental regulation in sustaining economic activity and financial stability at the local level.

The paper is structured as follows. Section 2 reviews the relevant literature on the environmental-financial nexus. Section 3 describes the data sources and methodological framework. Section 4 discusses the empirical results. Finally, sections 5 and 6 concludes with policy implications.

## 2. Literature review

Water and soil nitrate pollution is a severe and growing problem affecting ecosystem services (Fernández-Martínez et al., 2020) and human health (Bryan and Grinsven, 2013; Riaz et al. 2024). The major source of nitrates comes from anthropogenic activities, specifically the fertilizers used in agricultural practices (Riaz et al. 2024; Sakschewski et al 2025), and it is an increasing concern worldwide, reflected in the exponential growth of academic studies related to groundwater pollution since the 80s (Abascal et al, 2022). Additionally, firm performance in terms of profitability, competitiveness and short and long-term financial sustainability is highly dependent on the natural environment and the good status of the ecosystems (D'Amato et al., 2018; Winn & Pogutz, 2013). To address this issue, the EU Directive 91/676/CEE and its transposed Spanish Royal Decree 47/2022, of January 18, *on the protection of waters against diffuse pollution caused by nitrates from agricultural sources*, sets the thresholds to identify water bodies affected by nitrate pollution according. The source points are evaluated through a control and monitoring station network. According to the EU Directive, those areas that do not meet the thresholds must be designated as nitrate vulnerable areas. EU member states are required to report and monitor the status of ground and surface waters and enforce monitoring programs and action plans when those requirements are not met. For example, the compulsory application of codes of good agricultural practice to farmers. Nevertheless, this regulatory framework has proven not to have substantially changed the pattern of pollution in highly stressed areas like the semi-arid Mediterranean regions, which are more vulnerable to nitrate pollution (Pérez-Martín et al, 2016). Water, soil, or air pollution of any type is, in general terms, a negative externality that reduces local population welfare (Gulati and Kellenberg, 2013). Externality in this paper is defined following the definition of Perman (2011): an external effect generated from either production or consumption activities. In this concrete case, we just focus on production activities from the economic agents, with unintended consequences in both the production function of other economic agents and the utility function of the residents in the territorial area of the occurrence of the externality. Following the classification of externalities in Perman (2011), the case that is analysed in this work, land and water pollution by nitrates from intensive agricultural practices, is defined as a harmful externality originated by production activities. The absence of effective regulation against pollution affects firms' performance and residents' benefits from ecosystem services, and therefore overall social welfare. Our intuition to test for the presence of a harmful externality pollution problem in southeast Spain rests on the Pigou (1920) and the welfare economics approach. According to this, in the absence of a corrective policy, pollution externalities become market failures. In this case, we analyse the relationship between the market over-supply of pollution and the unintended negative consequences on overall firm performance. This occurs when external effects of production cause harm without any resulting consequences (i.e., punishment), and, as such, agents are not held accountable for them (Perman, 2011); or, in other words, it assumes that economic agents causing the pollution will not internalize the externality unless it is punished. Governmental measures to correct market failures, such as environmental pollution, frequently take the form of penalties, emission limits and standards, environmental taxes, or transferable prices (Wagner, 2003). Environmental taxation in the Pigouvian sense (Pigou, 1920) represents more than an optional tool, a necessary intervention to represent the true cost of goods and services and restore the private or firm interests and social welfare (Kopsidas et al., 2026). Nevertheless, according to the authors, the effective application of environmental Pigouvian taxation requires "state capacity", which means "robust administrative systems, credible monitoring mechanisms, and intergovernmental coordination". Therefore, effective internalization of harmful externalities like environmental pollution is not only an economic but also a governance challenge. Even when those measures, for example, in the case of tradable emission permits, are imposed on firms to control pollution, the result can be an alternative non-efficient allocation of resources and pollution (Bartram et al., 2022). In any case, those are policy measures used to correct the market failure. The alternative approach is based on the work of Porter (1991) and later in Porter and van der Linde (1995) on the positive association between the environmental performance and financial performance, the so-called 'Porter Hypothesis (PH)'. According to the PH the generators of the environmental damages, i.e., polluting firms, can benefit from undertaking corrective actions. The theoretical approach suggested by the authors supports the idea that pollution is a non-productive and non-efficient result of production, and any environmental improvement from the polluter firm is seen as a result of an innovation in the production process, product, or service, and would generate a positive impact on the firm's financial performance.

### *2.1. The nexus between environmental conservation and financial performance: the hypothesized pollution umbrella effect*

The environmental and climate-related risks have increased their attention in the last years in finance publications, being now considered an emerging field of research (Migliorelli, 2023; Sánchez-García et al, 2025). Nevertheless, it has been found that until now, academic papers have focused on climate to finance mechanisms rather than on environmental degradation (Sánchez-García et al, 2025) and other threats to environmental sustainability like biodiversity loss, pollution, or soil degradation (Migliorelli, 2023). In this paper, we aim to contribute to this academic gap by integrating actual data of environmental pollution in a spatial dependent version of the PH, arguing that environmental integrity is a prerequisite for long-term solvency of firms. Our first statement to be tested relies on the Porter (1991) and Porter and van der Linde (1995) arguments, according to which better environmental performance may increase firms' competitiveness through innovation and production process improvements. We argue that the absence of effective regulation against pollution may act conversely. The environmental pollution of land and water can act as a proxy for the absence of effective environmental regulation. Based on the research cited above, we are testing whether this evidence of ineffective pollution mitigation measures, reflected in the level of land and water pollution, is having negative consequences on firm performance. We initiate the following hypothesis:

**H1:** environmental pollution increases the probability of firm failure for companies located near polluted areas.

The second hypothesis relies on the idea that the impact of environmental pollution of firm performance can differ between firms belonging to different economic sectors in a specific location.

**H2:** the negative impact of pollution on firm performance is expected to be stronger among the service-sector firms.

To quantify the effect of environmental pollution on firm failure accurately, both the measurement of environmental pollution and the methodology are of critical importance. From our perspective, the pollution output must be directly incorporated into the equation as the effect of pollution generated by firms is noticeable very near the source of production, and its effects are suffered locally. Local dependence is the basis of the hypothesized *pollution umbrella effect,* which adds to the first and second hypothesis (H1 and H2) by proposing that environmental pollution is a localized externality.

The distinction between immediate and intermediate exposure allows us to identify the spatial decay of pollution effects and provides the empirical basis for testing the *pollution umbrella effect:*

**H3**: the size of the impact of environmental pollution on the probability of firm failure is higher as nearer the source of pollution.

Finally, based on previous literature on the structural distribution of the dependent variable, we set the fourth hypothesis around the spatial dependence of the firm failure.

**H4:** The probability of firm failure as the latent variable is spatially dependently distributed.

## 3. Data and methods

### *3.1. Data*

This section describes the data employed to examine the *pollution umbrella effect* and to estimate the probability of firm failure. All variables—financial, environmental, and socio-economic—are constructed at annual frequency to ensure temporal consistency. Firm-level financial data are obtained from the SABI (Iberian Balance Sheet Analysis System) database provided by the Orbis-Bureau Van Dijk, a financial database of firms operating in Spain and Portugal. The database includes balance sheets, profit and loss accounts, geographical coordinates, management information, and sector classification according to NACE Rev. 2.1 (NACE, 2025).

The empirical analysis focuses on firms located in the provinces of Murcia and Almería, southeast Spain, covering a five-year period based on the latest available data as of April 2025. The initial dataset contains 37,350 firm-year observations. After excluding observations with missing geographical coordinates, the final sample consists of 36,734 firms. The analysis includes firms across all sectors and size categories, ensuring broad representativeness of the regional economic structure. Financial variables are constructed from firms' annual accounts. These include total assets, equity, return on assets (ROA), return on equity (ROE), indebtedness, and firm age. Profitability (ROA, ROE) and indebtedness (Debt) are defined as the natural logarithm of the four-year average to smooth short-term fluctuations. Firm size (Size) is measured as the logarithm of the average total assets over the same period, while firm age (Age) is computed as the number of years since incorporation (as of 2025). Larger firms are expected to exhibit lower failure risk due to better access to financial resources (Assadian and Ford, 1997). In addition, firm's age is positively related to firm'survival (Esteve-Pérez and Mañez-Castillejo, 2008).

On the other hand, firm failure (Fr) is defined as a binary variable capturing financial distress. Following Altman (1983) and Maté-Sánchez-Val et al. (2018), a firm is classified as failed (Fr = 1) if it reports negative shareholders' equity for three consecutive years (t, t−1, t−2), or a combination of negative equity and missing information during that period. Otherwise, firms are classified as non-failed (Fr = 0). In the final sample, 5,614 firms (15.3%) are classified as failed, while 31,120 remain active.

To control for local economic conditions, we incorporate a socio-economic variable based on income per capita. Data are obtained from the Atlas of household income distribution published by the Spanish National Statistics Institute (INE), which provides information at highly disaggregated territorial levels. We use average net income per capita at the census section level for the most recent available year (2023). The variable is log-transformed and matched to each firm based on its geographical location, allowing us to control for micro-territorial economic heterogeneity. Environmental pollution is measured using groundwater nitrate concentration (NC) from the most recent four-year assessment under the EU Nitrates Directive (2016–2019). We focus on monitoring stations exceeding the regulatory threshold (NC > 50 mg/L), which are classified as being in "bad status."

To capture firms' exposure to pollution, we construct spatial metrics based on the distance between firm locations and polluted monitoring stations. Specifically, we define two measures of exposure reflecting different spatial scales. The first one accounts for the immediate exposure to polluted waters, it evaluates distances between a firm *i* and a polluted station/point *j* measured with $imm_i$, a density variable accounting the number of waters failing to comply identified within a 0,5 km radius of the firm. It takes the value 1 when the distance among them ( $\mathrm{d}_{ij}$) is inferior to 500 meters (0,5 km), so $imm_i = 1$, if

$d_{ij}$< 0.5 km. We also compute the intermediate exposure of firms to pollution ($int_i$) counting the control station of waters failing to comply the Directive threshold within a 2 km radius of the firm. The second matrix aims at gathering the intermediate exposure to pollution so that $int_i = 1$, if $d_{ij}$< 2.0 km. The distinction between immediate and intermediate exposure will allow the identification of the relevant distance for our hypothesized *pollution umbrella effect.* These distance thresholds are designed to capture the localized nature of environmental externalities. The distinction between immediate and intermediate exposure allows us to identify the spatial decay of pollution effects and provides the empirical basis for testing the *pollution umbrella effect*.

Table 1 provides descriptive statistics for the variables used to test the main hypothesis of this paper.

Table 1: Summary statistics

| Variable | Description | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| **Dependent Variable** | | | | | |
| Failure (Fr) | Dummy = 1 if the firm failed (Equity < 0) | 0.153 | 0.360 | 0 | 1 |
| **Environmental variables** | | | | | |
| imm | Count of polluted stations within 0.5 km | 0.04 | 0.20 | 0 | 2 |
| int | Count of polluted stations within 0.5 to 2 km | 0.21 | 0.55 | 0 | 4 |
| **Financial controls** | | | | | |
| Age | Years since incorporation | 18.4 | 12.1 | 1 | 98 |
| Size | Total Assets (Log) | 12.55 | 1.63 | 6.2 | 19.8 |
| ROA | Economic Profitability (Log) | 2.15 | 0.85 | 0 | 5.2 |
| ROE | Financial Profitability (Log) | 2.89 | 1.10 | 0 | 6.1 |
| **Socio-economic control** | | | | | |
| Income | Avg. net per capita income (Log) | 9.85 | 0.22 | 9.1 | 11.2 |

Source: Authors' own elaboration using RStudio.

*3.2 Methodological framework*

To empirically assess whether environmental degradation affects firm failure, we adopt a limited dependent variable framework extended to account for spatial dependence. This approach addresses three key features of the data: the binary nature of the outcome, the potential spatial clustering of firm failure, and the presence of spatially correlated shocks.

We model firm failure as a latent variable $y_i^*$, representing the unobserved propensity of firm $i$ to experience financial distress:

$$y_i^* = \alpha + \beta\, Env_i + \gamma'\, Fin_i + \delta\, Ctx_i + \varepsilon_i \tag{1}$$

where $Env_i$ measures firm $i$'s exposure to groundwater nitrate pollution, $Fin_i$ is a vector of firm-level financial variables (including size, profitability, indebtedness, and age), and $Ctx_i$ captures local socio-economic conditions. The error term $\varepsilon_i$ represents unobserved firm-specific factors. The observed binary outcome is defined as:

$$y_i = \mathbf{1}\,(y_i^* > 0) \tag{2}$$

where $y_i = 1$ indicates firm failure and $y_i = 0$ otherwise. Assuming $\varepsilon_i \sim N(0,1)$, the model is estimated using a probit specification:

$$Pr(y_i = 1 \mid X_i) = \Phi(\,\alpha + \beta\, Env_i + \gamma'\, Fin_i + \delta\, Ctx_i) \tag{3}$$

where $\Phi(\cdot)$ denotes the cumulative distribution function of the standard normal distribution. The parameter of interest is $\beta$, which captures the effect of environmental deterioration, i.e., the impact of proximity to nitrate-polluted groundwater ($NO_3$> 50 mg/L) on the likelihood of firm failure. Thus, $\beta$ captures the marginal effect of environmental exposure on the latent propensity of firm failure. However, firm failure is unlikely to be spatially independent. Firms located in close proximity may share similar economic environments, exposure to environmental degradation, and inter-firm spillovers. Ignoring this spatial structure may lead to biased or inefficient estimates. To address this issue, we introduce a spatial weights matrix $W$, constructed using a $k$-nearest neighbors' approach (with $k = 10$) based on geographical distance and row-standardized such that $\sum_j w_{ij} = 1$. We estimate two complementary spatial probit specifications. First, the spatial autoregressive model (SAR):

$$y^* = \rho W y^* + X\theta + \varepsilon, \qquad \varepsilon \sim N(0, I_N) \tag{4}$$

where ρ captures outcome interdependence across firms. A significant ρ indicates that firm failure exhibits spatial spillovers or contagion effects.

Second, the spatial error model (SEM):

$$y^* = X\beta + u, \quad u = \lambda W u + \varepsilon, \qquad \varepsilon \sim N(0, I_N) \tag{5}$$

where λ captures spatial correlation in unobserved shocks, such as local environmental or institutional factors. Comparing SAR and SEM specifications allows us to distinguish between direct spillover effects and spatially correlated omitted variables as sources of dependence.

A key identification concern relates to the non-random spatial distribution of firms. Firms may self-select into locations with specific economic or environmental characteristics, potentially biasing the estimated effect of pollution. To mitigate this concern, we include a rich set of firm-level financial controls and micro-territorial income variables, while spatial specifications account for residual local dependence. While this empirical strategy does not fully establish causality in a strict experimental sense, the stability of the estimated coefficients across alternative spatial specifications and exposure measures suggests that the results are not driven by broad territorial confounders. Moreover, we exploit variation in pollution exposure at different spatial scales to assess the spatial decay of environmental effects. The finding that pollution exposure is significant only at short distances is consistent with the interpretation of environmental degradation as a localized externality, in line with the *pollution umbrella effect*.

## 4. Empirical results

This section presents the empirical analysis of the relationship between environmental degradation and firm performance, focusing on whether exposure to nitrate pollution increases the probability of firm failure in southeast Spain.

### *4.1. Econometric specifications*

Building on the empirical framework outlined in Section 4, we estimate three complementary specifications to assess the robustness of the results: a baseline probit model, a spatial autoregressive (SAR) probit model, and a spatial error (SEM) probit model. This strategy allows us to evaluate both the direct effect of environmental exposure and the role of spatial dependence in shaping firm failure. The primary variable of interest is firm exposure to groundwater nitrate pollution, captured through two measures reflecting different spatial scales. The first variable, $imm_{it}$, measures immediate exposure by counting polluted monitoring stations within a 500-meter radius of the firm. The second, $int_{it}$, captures broader exposure within a 2 km radius. These variables operationalize the pollution umbrella effect and allow us to test for spatial decay in environmental impacts. We expect both coefficients to be positive, with stronger effects at shorter distances. The empirical specification also includes a set of firm-level financial controls—age, size, profitability (ROE, ROA), and indebtedness—which are standard determinants of firm survival. Consistent with the literature, firm size, age, and profitability are expected to reduce failure risk, while higher leverage is expected to increase it. Additionally, we include local income per capita as a proxy for micro-territorial economic conditions, which is expected to be negatively associated with firm failure.

The baseline model is specified as:

$$y_i^* = \beta_1\, imm_i + \beta_2\, int_i + \beta_3\, Age_i + \beta_4\, Size_i + \beta_5\, ROE_i + \beta_6\, ROA_i + \beta_7\, Debt_i + \beta_8\, Income_i + \varepsilon_i,\ \varepsilon_i \sim N(0,1) \tag{6}$$

To further account for spatial dependence, we incorporate the spatial specifications outlined in Section 4: equations 4 and 5. This enables us to evaluate whether the estimated effects are robust to alternative forms of spatial interaction and to capture potential spillovers and unobserved local heterogeneity.

*4.2. Baseline regression results: pollution umbrella effect.*

The estimation results, reported in Table 2, provide consistent evidence that environmental degradation constitutes a significant and spatially localized determinant of firm failure. This result is robust across baseline and spatial specifications, suggesting that the estimated relationship is not driven by unobserved spatial dependence or model-specific assumptions.

The key empirical finding emerges from the comparison between immediate and intermediate exposure to pollution. The coefficient $\beta_1$ associated with $imm_i$, which captures pollution intensity within a 500-meter radius, is positive and statistically significant across all specifications. This indicates that firms located in close proximity to nitrate-polluted groundwater face a systematically higher probability of failure, giving support to the H1. The magnitude of the $\beta_1$ coefficient illustrated in Table 2 column 1 (0.202, $p<0.05$) in the full sample indicates a positive and significant relationship with the probability of failure, and a greater impact than the age and profitability ratios. By contrast, the coefficient associated with $int_i$, which captures pollution exposure at a broader spatial scale, is not statistically significant in any specification. This result suggests that environmental externalities do not operate as diffuse regional factors, but rather as highly localized shocks affecting firms operating in immediate proximity to degraded ecosystems (H3).

Importantly, the stability of the coefficient on $imm_i$ across the baseline, SAR, and SEM models (0.181, $p<0.05$ and 0.203, $p<0.05$ respectively) strengthens the credibility of the results. In particular, the persistence of the effect after controlling for spatial spillovers (SAR) and spatially correlated unobserved heterogeneity (SEM) reduces concerns that the estimated relationship is driven by omitted local factors or broader territorial characteristics. While the empirical strategy does not fully establish causality, this consistency across specifications provides strong evidence that the pollution effect is not an artifact of spatial confounding. From an economic perspective, the sharp spatial decay observed in the results constitutes a key contribution. The fact that pollution effects are statistically significant only within a very short distance from the firm location supports the interpretation of environmental degradation as a localized externality (H3). This pattern is consistent with the theoretical framework proposed in the paper: nitrate pollution reduces the quality of local ecosystem services, thereby increasing operating costs or reducing demand conditions for nearby firms, with effects that dissipate rapidly over space.

| Table 2: Baseline and spatial SAR and SEM model results. | | | | | | |
|---|---|---|---|---|---|---|
| | (1) Baseline model | (2) Baseline model | (3) Spatial probit model SAR | (4) Spatial probit model SEM | (5) Spatial probit model SAR | (6) Spatial probit model SEM |
| | All NACE codes | Service sector: NACE =47; NACE>55 | All NACE codes | All NACE codes | Service sector: NACE =47; NACE>55 | Service sector: NACE =47; NACE>55 |
| Dependent variable | Failure rate | Failure rate | Failure rate | Failure rate | Failure rate | Failure rate |
| imm | 0.202** (0.094) | 0.296** (0.145) | 0.181** (0.040) | 0.203** (0.048) | 0.263** (0.041) | 0.298** (0.036) |
| int | 0.008 (0.025) | 0.015 (0.038) | 0.009 (0.665) | 0.008 (0.730) | 0.014 (0.710) | 0.015 (0.752) |
| Age | -0.023*** (0.001) | -0.026*** (0.002) | -0.023*** (0.000) | -0.022*** (0.000) | -0.026*** (0.000) | -0.027*** (0.000) |
| Size | -0.238*** (0.006) | -0.191*** (0.009) | -0.234*** (0.000) | -0.239*** (0.000) | -0.188*** (0.000) | -0.192*** (0.000) |
| ROE | -0.036*** (0.006) | -0.016* (0.008) | -0.035*** (0.000) | -0.036*** (0.000) | -0.016*** (0.058) | -0.016*** (0.000) |
| ROA | -0.091*** (0.008) | -0.117*** (0.012) | -0.092*** (0.000) | -0.091*** (0.000) | -0.117*** (0.000) | -0.118*** (0.000) |
| Debt | 0.316*** (0.011) | 0.267*** (0.014) | 0.313*** (0.000) | 0.317*** (0.000) | 0.266*** (0.000) | 0.270*** (0.000) |
| Income | -0.046*** (0.006) | -0.043*** (0.008) | -0.032*** (0.000) | -0.046*** (0.000) | -0.028*** (0.000) | -0.043*** (0.000) |
| Rho (autoregressive coefficient) | | | 0.120*** (0.000) | 0.189*** (0.000) | 0.132*** (0.000) | 0.201*** (0.000) |

*This table shows that immediate pollution (imm) increases failure risk, while the outer ring (int) is irrelevant. Note: standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.*

These results provide strong empirical support for H1 and H3, confirming that environmental degradation—when measured at a sufficiently fine spatial scale—acts as a relevant determinant of firm failure. Moreover, the evidence suggests that the economic impact of pollution is geographically bounded, reinforcing the notion of a *pollution umbrella effect* operating at the local level.

*4.3. Sector-specific regressions: Pollution umbrella effect in the service sector (H2)*

To test whether the impact of environmental degradation differs across economic sectors, we re-estimate the three model specifications using a subsample of service firms. This allows us to assess whether firms whose activity is more directly linked to local environmental quality are disproportionately affected by pollution exposure. The service sector is defined according to NACE Rev. 2.1 classification, focusing on activities with a stronger dependence on local demand conditions and ecosystem services, such as retail, tourism-related activities, professional services, and other service-oriented industries (see Appendix A). The results, reported in Table 2 (column 2), reveal a stronger pollution effect for service-sector firms. In particular, the coefficient associated with immediate pollution exposure ($imm_i$), $\beta_1$ (0.296, p<0.05), is consistently larger in magnitude across all specifications. This indicates that firms in the service sector are more sensitive to local environmental degradation, facing a higher increase in the probability of failure when located near polluted groundwater bodies.

Importantly, this result is robust across baseline and spatial models, suggesting that the amplified effect is not driven by differences in spatial dependence or omitted local factors. Rather, it reflects a structural heterogeneity in how environmental externalities affect different types of economic activity. From an economic perspective, these findings are consistent with the idea that service-sector firms rely more heavily on the quality of their surrounding environment. Environmental degradation may reduce local demand, diminish the attractiveness of the area, or negatively affect the provision of ecosystem services that are essential for service-based activities. As a result, pollution generates a stronger adverse effect on firm survival in this sector. The evidence supports hypothesis

H3, indicating that the *pollution umbrella effect* is not homogeneous across sectors but is significantly more pronounced among service-sector firms.

*4.4. Spatial regressions results. Location dependence of firm failure (H4).*

The spatial specifications provide strong evidence of location dependence in firm failure, supporting hypothesis H4. In particular, the spatial parameters estimated in both SAR and SEM models are positive and statistically significant across all specifications, indicating that firm failure exhibits a clear pattern of spatial clustering.

For the full sample, the spatial autoregressive coefficient in the SAR model is positive and significant ($\rho = 0.118, p < 0.01$), while the SEM specification yields a higher spatial dependence parameter ($\lambda = 0.183, p < 0.01$). These results indicate that firm failure is not independently distributed across space but is shaped by both direct spillover effects and spatially correlated unobserved factors.

In the service sector, spatial dependence is even more pronounced. The SAR model reports $\rho = 0.136$ ($p < 0.01$), while the SEM model yields $\lambda = 0.203$ ($p < 0.01$). This increase in magnitude suggests that firms operating in service activities are more strongly embedded in localized economic environments, where both inter-firm interactions and common shocks play a more significant role. From an economic perspective, the significance of the SAR parameter reflects the presence of localized contagion mechanisms: the probability of failure for a given firm increases when neighboring firms experience financial distress. Such spillovers may arise through demand linkages, shared customer bases, or network-based interactions. At the same time, the SEM results indicate that spatial dependence is also driven by unobserved territorial factors, such as environmental conditions, institutional quality, or localized economic dynamics.

Taken together, these findings suggest that spatial clustering in firm failure is the result of both direct interaction effects and shared exposure to local conditions. Importantly, the stronger spatial dependence observed in the service sector highlights the role of geographically bounded economic structures, where external shocks—such as environmental degradation—propagate more intensely across firms. These results reinforce the appropriateness of a spatial econometric framework, as standard models assuming independent observations would fail to capture these localized dynamics. More broadly, they indicate that firm survival is not only determined by internal financial characteristics or environmental exposure, but also by the spatial context in which firms operate. Finally, the behavior of financial controls remains consistent with theoretical expectations. Indebtedness emerges as the main driver of failure, while firm age, size, and local income act as stabilizing factors, supporting the internal validity of the empirical specification.

### *4.5. Marginal effects*

The interpretation of the coefficients reported in Table 2 is not direct as the reported impact of the regressors coefficients on the independent variable is non-linear (Martinetti and Geniaux, 2017). Therefore, the estimated coefficients cannot be interpreted directly as changes in the probability of firm failure. To provide a clear interpretation of the results we compute marginal effects [1] for both the standard probit model and the spatial specifications. These results allow us to quantify the *pollution umbrella effect* about the suggested spatial decay in the impact of the negative externality. Moreover, in the case of the spatial autoregressive (SAR) probit specifications, as mentioned in the methodology section, the decomposition of marginal effects allows us to distinguish between the direct effect of a change in any of the explanatory variables on the probability of failure of the $i^{th}$ firm observation; and on the indirect effect, i.e.: the impact of a change in the covariates in *i*'s firm neighbors in $i^{th}$ firm probability of failure, or spillover effect. Total average effect is the sum of direct and indirect effects.

Table 3: Marginal effects of probit estimations.

| Variables | All NACE codes (1) | Service sector (2) |
|---|---|---|
| imm | 0.040**<br>(0.0186) | 0.066**<br>(0.032) |
| int | 0.002<br>(0.005) | 0.003<br>(0.008) |
| Age | -0.004***<br>(0.000) | -0.006***<br>(0.000) |
| Size | -0.047*** | -0.042*** |

[1] All estimations were carried out using the library *ProbitSpatial* of RStudio (Martinetti and Geniaux, 2017)

| | | |
|---|---|---|
| | (0.001) | (0.002) |
| ROE | -0.007*** (0.001) | -0.003*(0.002) |
| ROA | -0.018*** (0.002) | -0.026*** (0.003) |
| Debt | 0.062*** (0.002) | 0.059*** (0.003) |
| Income | -0.0092*** 0.0012 | -0.0095*** 0.0018 |
| *Note: standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.* (*) | | |

Table 3 report the marginal effect of standard probit estimated for the whole sample firms belonging to any sectoral activity (column 1), and for the service sector firms (column 2). Regarding the environmental pollution exposure, the results show that the average marginal effect of a change in one additional unit in the immediate pollution (*imm:* count of the number of polluted stations in a radio from the firm of 500 meters) increases the probability of failure rate by 4 %. The effect is considerably stronger among service-sector firms (see Appendix A), where the probability of failure increases by around 6.6%. By contrast, the intermediate exposure (*int*), remains statistically insignificant across all specifications, reinforcing the hypothesis that environmental externalities operate primarily at very short spatial distances. The spatial marginal effects reported in Table 4 confirm the robustness of these findings. In the SAR specification, immediate pollution exposure (*imm*) generates both direct and indirect effects on firm failure. For the full sample, the direct effect of indicates that one additional polluted station within 500 metres increases the probability of failure by 3.6%, while the indirect spillover effect contributes an additional 0.5%. Consequently, the total marginal effect reaches approximately 4.1%. In the service sector, the magnitude of the effect is substantially larger. The direct effect indicates that immediate exposure to pollution increases the probability of failure by 5.3% for a service sector company, while neighboring spillovers, pollution exposure of close firms, contribute an additional 0.8%, resulting in a total effect of approximately 6.1%.

The SEM specification produces very similar average marginal effects, confirming the stability of the results across alternative spatial structures. In particular, the estimated average marginal effect of immediate pollution exposure reaches approximately 5.9% for service-sector firms. This consistency across spatial specifications strengthens the interpretation that environmental degradation constitutes a relevant determinant of firm failure rather than an artefact of omitted spatial heterogeneity. The remaining control variables display the expected signs and are highly consistent across specifications. Firm age and firm size are negatively associated with the probability of failure, indicating that older and larger firms exhibit greater financial resilience. Similarly, higher profitability ratios (ROA and ROE) significantly reduce the likelihood of failure, whereas indebtedness remains the strongest determinant of financial distress. Local income levels also reduce failure probabilities, suggesting that firms located in economically stronger areas benefit from more favorable local demand and business conditions. Overall, the marginal effects analysis confirms that environmental degradation exerts a statistically significant and economically meaningful impact on firm survival. More importantly, the results demonstrate that this effect is spatially concentrated and particularly severe for service-sector firms, whose economic activity depends more directly on the quality of local ecosystem services.

Table 4: Marginal effects of spatial probit estimations (SAR and SEM specifications). All sector firms in columns (1) and (2) and service sector firms in columns (3) and (4).

| | All NACE | | | | Service Sector | | | |
|---|---|---|---|---|---|---|---|---|
| Variables | SAR (1) | | | SEM (2) | SAR (3) | | | SEM (4) |
| | Direct | Indirect | Total | Average | Direct | Indirect | Total | Average |
| imm | 0.036**<br>(0.017) | 0.005**<br>(0.002) | 0.041**<br>(0.019) | 0.040**<br>(0.020) | 0.058**<br>(0.028) | 0.009**<br>(0.004) | 0.067**<br>(0.033) | 0.066**<br>(0.031) |
| int | 0.001<br>(0.004) | 0.000<br>(0.000) | -0.002<br>(0.004) | 0.001<br>(0.004) | 0.003<br>(0.008) | 0.000<br>(0.001) | 0.003<br>(0.009) | 0.003<br>(0.010) |
| Age | -0.004***<br>(0.000) | -0.001***<br>(0.000) | -0.005***<br>(0.000) | -0.004***<br>(0.000) | -0.006***<br>(0.000) | -0.001***<br>(0.000) | -0.007***<br>(0.000) | -0.006***<br>(0.000) |
| Size | -0.046***<br>(0.001) | -0.006***<br>(0.000) | -0.052***<br>(0.001) | -0.047***<br>(0.001) | -0.042***<br>(0.001) | -0.006*<br>(0.000) | -0.048*<br>(0.000) | -0.042***<br>(0.001) |
| ROE | -0.007***<br>(0.001) | -0.001***<br>(0.000) | -0.008***<br>(0.001) | -0.007***<br>(0.001) | -0.003*<br>(0.001) | -0.000***<br>(0.000) | -0.004***<br>(0.002) | -0.003*<br>(0.001) |
| ROA | -0.018*** | -0.002*** | -0.021*** | -0.018*** | -0.026*** | -0.004*** | -0.030*** | -0.026*** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (0.001) | (0.000) | (0.002) | (0.001) | (0.002) | (0.000) | (0.002) | (0.002) |
| Debt | 0.062*** (0.001) | -0.008*** (0.000) | 0.070*** (0.002) | 0.062*** (0.001) | 0.059*** (0.003) | 0.009*** (0.000) | 0.068*** (0.003) | 0.059*** (0.002) |
| Income | -0.006*** (0.001) | -0.001*** (0.000) | -0.007*** (0.001) | -0.009*** (0.001) | -0.006*** (0.002) | -0.001*** (0.000) | -0.007*** (0.002) | 0.009*** (0.001) |
| *Note: standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.* (*) | | | | | | | | |

## 5. Conclusions

Environmental conservation and pollution emission reduction policies in the EU are today at the root of the EU Commission Agenda for 2030, not only from an ecosystem conservation perspective but also to ensure the future of regional economic development within the EU. The main objective of EU Directives to protect the environment from nutrient pollution, i.e., the Nitrates Directive (ND) and the Water Framework Directive (WFD), includes the evaluation of the minimum requirements for the “good status” of ecosystems, defining thresholds of pollution emissions and enforcing EU states to monitor and report periodically the status of the ecosystems under evaluation. Nevertheless, the results of these reports show that there are many EU countries where the conservation status is poor or bad in a great part of the ecosystems; consequently, it can be argued that current frameworks of environmental regulation are not enough to effectively control pollution and therefore to maintain the ecosystem services provision to secure firm survival (D’Amato et al., 2024; Winn and Pogutz, 2013).

This study builds on the results of the last evaluation from the Spanish government according to the EU Nitrates Directive of Spanish groundwaters for the period 2016-2019 to examine the degree of exposure of firms to water and soil pollution. This is a real environmental status indicator that provides a natural experiment to evaluate the effect of exposure to high levels of pollution on firms’ financial distress. Through a series of empirical exercises, three main research questions are estimated and answered. The main findings are discussed below.

First, regarding the objectives of the EU Nitrates Directive of reducing nitrate pollution, it has been proven not to have substantially changed the pattern of pollution in highly stressed areas like semi-arid Mediterranean regions in Spain (Pérez-Martín et al, 2016).

Our baseline econometric specification builds on existing literature about the potential impact on firm performance, measured with the probability of failure, of firms' exposure to high levels of pollution; testing the dependence of the economic activity on the natural environment and the good status of the ecosystems. We called this the *pollution umbrella effect*. It allows us to determine the significant radio of impact in terms of distance to pollution by using spatial econometric techniques. This effect is statistically significant for firms belonging to any economic activity within a radio of 500 metres. Recent literature exploring the impact of pollution on firm performance confirms this finding. Maté-Sánchez-Val and Aparicio-Serrano (2023) demonstrate that firm performance is negatively related to the proximity of the firms to eutrophicated coastal waters within 600 meters. In the case of air pollution, for example, Xue et al. (2021) also found that the visible effects of air pollution are determinants of human capital location decisions. These authors confirmed that firms facing high levels of pollution present lower levels of total factor productivity and firm value than firms located in healthier environments, which they call the *brain drain* effect.

Second, the exposure to excessive pollution levels is more harmful for firms in the service sector, which can be understood from the ecosystem – organization dependence. This result supports the social-ecological systems research main paradigm that social and economic systems are dependent on the biosphere (Folke et al 2016). In this specific case, our results highlight that businesses operating income is closely dependent on the ecosystem services provision (Win and Pogutz, 2013, p. 220) and their vulnerability to "*shortages in the availability of these services: depletion of fish stocks threatens global fisheries and companies operating in the food industry; growing pressure on water resources affects both the supply and the quality of water and undermines businesses' continuity in sectors such as agriculture, forestry, beverages, or energy."* For example, the aesthetic services from water and coastal ecosystems are key to maintaining businesses in the tourism sector (Arabadzhyan et al., 2021). Moreover, the good functioning of ecosystem services provides an appropriate framework for the development of local economic activity: mitigation of pollution, protection against floods, or the maintenance of the ecological context (D'Amato et al., 2024). Therefore, our findings add empirical evidence on the hypothesis that environmental pollution is a non-neutral factor in firm survival. Poor environmental status (proxied by nitrate pollution) acts as a location-specific stressor that significantly increases the likelihood of firm failure.

Finally, we further investigate the spatial interaction among firms, and our results show a statistically significant autoregressive coefficient in the spatial econometric specifications. This provides additional insights on the spatial dependence structure in the failure rate of firms, suggesting that this structure is positively correlated so that firms surrounded by failed firms have a higher probability of failure, and conversely.

## 6. Managerial and policy implications

This study provides several managerial implications and policy recommendations. First, regarding polluting firms, business managers should make additional investments to control water eutrophication, aiming to keep $NO_3$ levels below the 50 mg/L threshold established by the EU Nitrates Directive. The impact of these additional investments not only affects the financial stability of firms but also improves the probability of survival of their peers. This aligns with Lovins et al (1999) approach that some changes in how companies run their business cannot only improve competitiveness and profits, but also reduce harm to the environment and even preserve or restore natural resources. Second, non-polluting firms should demand governmental action that effectively addresses the financial issues caused by the impoverishment of the level of provision of ecosystem services due to environmental pollution. Third, EU Directives must include enforcement of the policies by incorporating additional measures to deter illegal practices harming the natural environment and enforcing the accomplishment of the maximum threshold of pollution emissions. Finally, local governments should impose environmental taxes on pollution as market mechanisms have demonstrated to be unable to account for the negative externalities (Kopsidas et al., 2026).

These recommendations align with previous research on the area, highlighting that the costs and responsibilities for the social-ecological impacts of agriculture (and as such of nitrogen pollution) need to be held at different scales, including -but not limited to- firms, national to local governments, and European laws and legislation (Jiménez-Aceituno et al 2025). Other relevant actors, such as retailers in the case of the agriculture sector, although out of the scope of this work, hold great power to generate their own private standards and certification systems to regulate, among other issues, environmental pollution. This also constitutes an entry point for reducing nitrogen pollution; however, the role of these actors in keeping the system in its current state has also been studied (e.g., by paying very low prices for agricultural products) (Jiménez-Aceituno et al 2025).

We argue that, in a complex social-ecological system, coordination and accountability of the different key actors across scales and sectors are fundamental to tackling local eutrophication and broadly contributing to staying within the nitrogen planetary boundary.

## Appendix A. Service sector firms

We have selected service firms in the following NACE Rev.2 section in order to capture the economic activities within the service sector which tend to be more dependent on their local environment.

| NACE Rev. 2 | |
|---|---|
| Sections | Description |
| G<br>47 | Wholesale and retail trade, repair of motor vehicles and motorcycle<br>Retail trade, except of motor vehicles and motorcycles |
| H | Transportation and storage |
| I | Accommodation and food service activities |
| J | Information and communication |
| K | Financial and insurance activities |
| L | Real estate activities |
| M | Professional, scientific and technical activities |
| N | Administrative and support service activities |
| O | Public administration and defence; compulsory social security |
| P | Education |
| Q | Human health and social work activities |
| R | Arts, entertainment and recreation |
| S | Other service activities |
| T | Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use |
| U | Activities of extraterritorial organisations and bodies |
| Source: NACE Rev. 2 – Statistical classification of economic activities in the European Community (Eurostat) | |

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