

Market Failures and Environmental Innovation: A Firm Size Perspective in Pre-Brexit UK

This study extends knowledge on Environmental Innovation (EI) by exploring the multifaceted barriers that deter firms from embracing EI strategies, a vital component for mitigating the impact of climate change. Drawing on market failure theory, this study examines how these barriers are disproportionately encountered by firms based on size, within the context of the UK amidst the Brexit transition period. The findings underscore significant market failure-driven obstacles, including regulatory frameworks, financing difficulties, economic risks, and information gaps, which notably hinder firms engaged in EI compared with firms engaged in broader innovation activities. Furthermore, it sheds light on the variances in challenges faced by firms of different sizes, enriching the discourse on the applicability of market failure theory to environmental innovation dynamics. This contribution is pivotal in disentangling the barriers to EI from wider innovation barriers, thus enabling more focused EI policy interventions, as well as guiding future research in fostering a conducive environment for EI amidst changing regulatory landscapes.

Keywords: environmental innovation, innovation barriers, regulation, United Kingdom

1. Introduction and Background

The detrimental environmental impacts of business activities, notably increased pollution, waste accumulation, biodiversity loss, and escalated greenhouse gas emissions, are now widely acknowledged as substantial contributors to the prevailing climate crisis. These adverse outcomes not only cast a shadow on societal well-being but also intensify the urgency for innovative solutions to counteract climate change (Houdet, Trommetter, and Weber 2012; Addison et al. 2020; Downie and Stubbs 2013; Jaffe, Newell, and Stavins 2005).

In this context, innovation emerges as a key mechanism, with the adoption and development of environmentally focused products, services, and processes, supported by conducive policy and market frameworks, being imperative for businesses aiming to mitigate such challenges (Rennings 2000; IPCC 2022; World Economic Forum. 2022). Despite this, the journey towards environmental innovation (EI) is fraught with significant barriers that deter firms from undertaking activities essential for confronting the looming environmental crises (Stucki 2019; Dias Angelo, Jose Chiappetta Jabbour, and Vasconcellos Galina 2012), underlining the importance of identifying and understanding these innovation barriers to develop effective policy instruments and guidance (D'Este et al. 2012).

Embarking on EI enables firms not only to mitigate adverse environmental impacts through initiatives such as pollution reduction, waste minimisation, and efficient resource use but also to seize commercial opportunities that bolster profitability and competitiveness (Forsman 2013; Castellano et al. 2022). This distinctive dual focus on environmental and commercial benefits sets EI apart from general forms of innovation, potentially lowering the marginal costs associated with reducing a firm's environmental footprint (Jaffe, Newell, and Stavins 2005). Moreover, the sphere of EI has seen the rise of new industries like renewable energy technologies and electric vehicles, spurred by regulatory pressures for environmental impact reduction and shifts towards a circular economy and industrial symbiosis, further emphasising its pivotal role in environmental performance enhancement (Horbach, Rammer, and Rennings 2012; Borghesi, Cainelli, and Mazzanti 2015; Karmaker et al. 2021).

Driven by a combination of internal and external factors including stakeholder influences, regulatory frameworks, cultural norms, and environmental awareness, EI is distinguished by its unique motivations compared to general innovation (Forsman 2013; Castellano et al. 2022; Carfora, Scandurra, and Thomas 2021; Doran and Ryan 2016; Ullah et al. 2022; Ghisetti and Pontoni 2015). Its significance is particularly pronounced in sectors with high pollution levels, highlighting its essential role in mitigating environmental impacts (Del Río, Peñasco, and Romero-Jordán 2016). Yet, the path of EI is marked by unique challenges, with research like that by Costa-Campi et al. (2014) and Ghisetti et al. (2017) initiating a discussion on the distinct barriers, such as market-related hurdles and financial constraints, faced by firms engaging in EI. Although Stucki (2019) and Pinkse et al. (2024) delve deeper into these issues, Souto and Rodriguez (2015) suggest a broader impact of these barriers on EI firms, despite some constraints in their study's scope and analysis.

This burgeoning body of research has begun to illuminate the specific barriers to EI (Bergek, Hellsmark, and Karltorp 2023; Horbach, Oltra, and Belin 2013; Sala and Silva 2013; Pinkse, Demirel, and Marino 2024; Arvanitis et al. 2017). However, gaps remain (Keskin et al., 2013; Pinget et al., 2015). Particularly, in the nuanced understanding of these challenges across different firm sizes and the disproportionate impact on EI relative to general innovation. Such an understanding is critical, given the significant contribution of small and medium-sized enterprises (SMEs) to the economy and their pronounced environmental impact, which further complicates the landscape of EI barriers (Pinget et al., 2015; Passario et al., 2023; Calogirou et al., 2010; D'Este et al., 2012). Market failures, driven by the externalities associated with environmental impacts and the difficulties in fully capturing the benefits of technological

innovation, are a primary cause of EI underinvestment, necessitating a deeper exploration through regulatory interventions and beyond (Jaffe, Newell, and Stavins 2005; Narassimhan, Myslikova, and Gallagher 2024). Especially, in the nuanced understanding of these challenges across different firm sizes and the disproportionate impact on EI relative to general innovation.

Addressing these identified gaps through empirical examination can empower firms to navigate these barriers more effectively, making EI a more viable and appealing strategy while guiding policymakers in targeted intervention efforts (Bergek et al., 2023). This study aims to bridge the gaps identified in the literature by employing an empirical approach to examine how firms can more effectively overcome barriers to EI, thereby enhancing the attractiveness and feasibility of EI strategies. Additionally, it seeks to inform policy makers about targeted interventions. Utilising market failure theory, this research provides a nuanced analysis of the barriers encountered by firms engaging in EI, with a particular focus on how these challenges differ according to firm size. The investigation delves into the dynamics of EI within the UK context during the pivotal period leading up to the Brexit referendum, aiming to unearth novel insights into how market failures impact EI, supported by an in-depth examination of innovation barriers amid significant regulatory changes.

Grounded in market failure theory, this study offers a comprehensive evaluation of the unique obstacles faced by firms pursuing EI, as opposed to general innovation endeavours. The findings contribute to the field in three key ways. Firstly, it enriches knowledge on market failure theory by demonstrating its direct application to the context of EI; thereby, highlighting its relevance and utility. Secondly, it identifies and elucidates the specific barriers that are disproportionately challenging for EI, such as regulatory complexities, financial constraints, economic uncertainties, and knowledge gaps, highlighting the role of both UK-specific and broader EU regulations. Finally, it investigates the interplay between these barriers and firm size, providing insights into how the effects of these obstacles vary among businesses of varying scales. This detailed examination of the EI barriers not only advances academic discourse by clarifying the precise difficulties faced by firms but also offers guidance for future research and policy formulation.

The paper continues by examining the market failure and environmental challenges literature, highlighting significant barriers including regulatory, financial, and informational issues encountered by firms. It then outlines the data sources and research methods, leading to the presentation and analysis of results. The discussion synthesises the study's findings, and the conclusions propose directions for future research and policy recommendations.

2. Hypotheses Development

This section delves into the intricate relationship between market failures, economic risks, and other economic factors, emphasising their pivotal role in shaping the landscape for EI. Market failures, particularly in the allocation of resources towards environmental goods, underscore the inefficiencies inherent in markets, which are ill-equipped to fully capture the societal value of EI. By weaving together theoretical insights with empirical evidence, a nuanced understanding of the economic dimensions that curtail the advancement of EI is constructed; thereby, setting the stage for a comprehensive exploration of the hypotheses that emerge from these dynamics.

Market Failure

The British economist Arthur Cecil Pigou (1877-1959) reconceptualised economics as a theory of economic welfare and a logic of policy analysis. In his seminal work "The Economics of Welfare" (1920), he laid the foundational concepts of market failures. In the realm of economic

theory, market failures represent critical points of analysis, particularly concerning the efficient allocation of resources to environmental goods. These failures arise from systemic inefficiencies in markets that are unable to adequately provide for environmental benefits. Such benefits, which include reduced emissions and the sustainable use of resources, are quintessential examples of public goods characterised by their non-excludability and non-rivalrous nature. These characteristics present profound challenges to traditional market operations, as they do not inherently incentivise firms to engage in EI.

The societal benefits conferred by EI often far surpass the immediate gains accrued to the innovating firms (Stiglitz and Rosengard, 2015). This discrepancy fosters a scenario where the collective value of environmental innovations markedly outweighs the private returns realised by individual entities, leading to a market failure. This failure is further underscored by the systemic underinvestment in EI, a phenomenon well-documented in the economic literature (Baumol & Oates, 1988; Oltra, 2008). The implications of this market failure are profound, necessitating a nuanced understanding of its mechanisms and impact on environmental innovation.

Economic Risks and Other Economic Factors

The journey towards EI is not merely an avenue for achieving sustainability but also a path fraught with economic risks and challenges. The divergence between the pursuit of private returns and the aim to deliver social benefits underscores a fundamental dilemma in EI. Firms, driven by the pursuit of private gains, often hesitate to commit to innovations that, while beneficial to society, may not yield immediate financial rewards (Skard, Jørgensen, and Pedersen 2021). This hesitancy is exacerbated by financial barriers not merely of a monetary nature but rooted in the market's inability to appropriately value and reward the environmental externalities generated by EI (Stern and Valero 2021; Bergek, Hellsmark, and Karltorp 2023; Bohnsack, Pinkse, and Kolk 2014).

These risks are diverse, encompassing the uncertainty of returns due to the long-term nature of environmental benefits, the technological risks associated with pioneering new environmental solutions, and the regulatory risks linked to evolving environmental policies. The market's inability to recognise and properly reward the societal benefits of EI further amplifies these risks.

EI is driven by a combination of internal and external factors, including stakeholder influences, regulatory frameworks, cultural norms, environmental awareness, investment pressures, and the potential for premium pricing on eco-friendly goods (Forsman 2013; Castellano et al. 2022; Carfora, Scandurra, and Thomas 2021; Doran and Ryan 2016; Ullah et al. 2022). The literature's consensus on the drivers of EI, categorised into technology push, market pull, policy push-pull, and firm-specific factors, underscores the unique motivations behind EI compared to general innovation (Ghisetti and Pontoni 2015). Moreover, the prevalence of EI in highly polluting sectors further highlights its importance in mitigating environmental impacts (Del Río, Peñasco, and Romero-Jordán 2016).

Consequently, firms engaged in EI encounter a distinctive set of economic challenges, less common among companies focused on non-environmental innovations (Stern and Valero 2021). This elevated risk profile does not necessarily manifest in significant differences in other economic factors, including personnel shortages, monopolies, and uncertain demand, compared to their counterparts not engaged in EI. However, it emphasises an increased exposure to economic vulnerabilities intimately connected to the nature of their innovations (Stern and Valero 2021; Bergek, Hellsmark, and Karltorp 2023; Bohnsack, Pinkse, and Kolk 2014). From this analysis, Hypothesis 1 is proposed, suggesting that:

H1: Firms engaged in EI are likely to face significantly greater economic risks yet may not exhibit significant differences in other economic barriers compared to firms not involved in EI.

Financial Barriers

Concurrently, the financing landscape for EI reveals a paradox. Despite the ostensible accessibility of finance across various sectors, EI projects face pronounced challenges due to the perceived risks and uncertainties intrinsic to these endeavours. The increased risk and uncertainty manifests in increased financing costs, underscoring the market's struggle to quantify and reward the broader environmental benefits of EI (Jaffe, Newell, and Stavins 2005).

For example, Verdolini et al. (2021) explore the unique financing dynamics of EI projects, highlighting the marked distinction from their non-environmental counterparts. The essence of the challenge resides in the heightened perceived risks and uncertainties intrinsic to EI, which are manifested in increased financing costs. This rise in costs reflects the market's difficulty in adequately quantifying and rewarding the broader environmental benefits engendered by EI. Furthermore, Pellegrino and Savona (2017) underscore the significance of financial barriers across the innovation spectrum, but the unique market dynamics further elucidate why firms engaged in EI face distinct barriers compared to those in general innovation (Verdolini, Sovacool, and Drummond 2021).

This scenario is further complicated by the unique market dynamics that EI projects entail. Unlike general innovation, EI is plagued by financial barriers that stem from the positive externalities and public good nature of environmental benefits, creating a disparity between the societal value of these innovations and the private value accruing to the innovating firm (Stiglitz and Rosengard, 2015). Although finance availability may not differ significantly, the financing of EI projects is often encumbered by higher perceived risks and uncertainties, leading to elevated financing costs and a resultant phenomenon of underinvestment; thereby, exacerbating the economic risks for firms engaged in EI (Baumol and Oates 1988; Oltra 2008). Consequently, Hypothesis 2 is proposed:

H2: While innovation costs and financial availability may not markedly differ for environmental innovators, the increased risk and uncertainty inherent in EI will significantly influence the cost of finance.

Regulatory Barriers

Regulatory frameworks serve as pivotal mechanisms in rectifying market failures, particularly those contributing to environmental degradation. By aiming to realign market incentives with societal welfare, these interventions seek to internalise the negative externalities associated with environmental harm, thus, fostering an environment conducive to EI (Jaffe, Newell, and Stavins 2005). Despite their intent, regulatory measures often impose significant compliance costs and administrative burdens, inadvertently establishing barriers to EI (Narassimhan, Myslikova, and Gallagher 2024). This challenge is notably less significant in the domain of general innovation, where the congruence between private and social benefits is more apparent (Bergek, Hellsmark, and Karltorp 2023).

The literature presents a nuanced view on the impact of regulation on innovation, indicating that the effects can vary based on factors such as the type of innovation involved (Blind 2012). Within the context of EI, a complex relationship with regulation has been documented, where some scholars argue that regulation stimulates innovation by setting environmental standards (Porter and Van Der Linde 2017), while others contend it acts as a

hindrance, citing increased compliance costs and the introduction of regulatory uncertainty (Clausen et al. 2023; Shao et al. 2020). Although instances of negative impacts have been identified (Borsatto and Bazani 2021), environmental regulations, pivotal for firms engaged in EI, generally show a positive correlation with EI.

In the lead-up to the EU referendum and subsequent years, the distinction between EU and UK law gained prominence (Obuoforibo 2021; De Troyer 2020), with EU regulations frequently appearing in media as a concern by firms. The debate around the UK's regulatory autonomy, encapsulated in the intent to repeal all inherited EU laws by December 2023 (HM Government. 2018), highlighted the complex political and economic dimensions of this issue. This move, aimed at "taking back control" of UK laws (HM Government 2018, 1), was later refined, leading to a selective approach under the Retained EU Law (Revocation and Reform) Act 2023 amid concerns over potential economic repercussions (Matikonis and Garavan 2023). The anticipation of the EU referendum and the subsequent uncertainties regarding future regulatory alignments between the UK and the EU further complicated the regulatory environment for firms dedicated to EI (Matikonis and Garavan 2023).

This ongoing debate is enriched by analyses that dissect the dual nature of environmental regulation's impact on innovation. Regulations can indeed act as catalysts for innovation, driving firms to develop new solutions to meet environmental standards (Blind, 2012, Porter and Van Der Linde, 2017). Conversely, they may also hinder innovation by elevating compliance costs and fostering uncertainty about future regulatory changes (Blind, 2012, Palmer and Oates, 2018). The influence of regulation on EI is evidently contingent on a variety of factors, including the specific characteristics of the firm (Shao et al. 2020) and the nature of the regulatory measures (Lanoie et al. 2011). The third hypothesis emerging from this discourse, proposes that:

H3: Firms engaged in EI face greater regulatory barriers compared to those engaged in general innovation.

Informational Barriers

Regulatory frameworks not only mandate firms to venture into new areas of innovation but also impose informational demands that can stretch beyond their current capabilities and knowledge bases (Horbach, Oltra, and Belin 2013; Stern and Valero 2021; Pinkse, Demirel, and Marino 2024). This scenario places EI firms in a position where they must continuously seek out, assimilate, and apply new information to remain compliant and competitive, often requiring collaboration with external entities to bridge these informational gaps.

Furthermore, informational deficits represent a critical barrier to EI, exacerbated by the rapidly evolving nature of environmental technologies and markets (Kolk and Pinkse 2008), alongside the intricacies involved in forecasting long-term environmental impacts and regulatory shifts (Pinkse, Demirel, and Marino 2024). Research highlights the intensive information and knowledge requirements inherent in EI (Horbach, Oltra, and Belin 2013; Pinkse, Demirel, and Marino 2024), often necessitating expertise and data beyond a firm's existing capabilities. Firms involved in EI have therefore been found to collaborate more with external partners compared with firms engaged in other forms of innovation (De Marchi 2012). This demand for external information, sometimes sourced from academia and research institutions (Moraes Silva, Lucas, and Vonortas 2020), underscores the heightened informational challenges associated with EI compared to more conventional innovation pathways.

Market failures due to informational deficits can arise from several sources. In the context of open innovation, Hewitt-Dundas & Roper (2018) identify three sources of market

failure relating to informational deficits: (1) a lack of information about the benefits, (2) a lack of information about potential partners' capabilities, and (3) a lack of information about partner trustworthiness. Another potential cause of information deficit is a lack of firm-level research and development (R&D), which can arise because of market failures and positive externalities. A lack of R&D can limit the development of firm-level absorptive capacity (Cohen and Levinthal 1989), thus, limiting knowledge spillovers from R&D. Previous studies have also highlighted the importance of technology transfer (de la Tour, Glachant, and Ménière 2011) and knowledge spillovers in EI (Noailly and Shestalova 2017). These knowledge spillovers can arise from publicly supported R&D, providing firms with information for EI. However, firms also need to have absorptive capacity to assimilate and benefit from information flows arising from knowledge spillovers (Cohen and Levinthal 1990).

The fourth hypothesis is formulated against this backdrop:

H4: Firms engaged in EI are significantly more likely to face barriers from informational deficits compared with firms focusing on more general innovation.

Large Firms Versus SMEs

The discourse on market failure extends to the delineation between large firms and SMEs; especially, in how these entities navigate informational and regulatory barriers. The concept of information asymmetry, a cornerstone of market failure literature, highlights the challenges that arise when disparities in information access and quality lead to suboptimal outcomes (Cohen and Levinthal, 1989). Large firms, with their substantial resources and established networks, are in a relatively better position to mitigate these asymmetries (Hewitt-Dundas 2006; Narula 2004). They can invest in internal R&D to develop proprietary knowledge, engage in collaborations with external knowledge institutions, and participate in industry consortia that collectively address informational deficits (Roper and Turner 2020; Audretsch and Belitski 2020; Kijkasiwat and Phuensane 2020). This capacity to overcome informational barriers aligns with the market failure literature (e.g. Stiglitz and Rosengard, 2015), suggesting that firms with greater resources and network capabilities can navigate informational asymmetries more effectively, thereby reducing the market's failure to allocate resources optimally for EI.

Regulatory barriers stem from government interventions designed to correct market inefficiencies, particularly those related to negative externalities of environmental degradation. While these interventions are necessary to encourage EI, they can also introduce compliance costs and administrative burdens, which act as barriers. However, large firms have a strategic advantage in this area: their ability to influence regulatory frameworks and their greater capacity for compliance can diminish the impact of these barriers (Lanoie, 2011; Shao et al., 2020). The market failure literature (e.g. Stiglitz and Rosengard, 2015) also acknowledges that larger entities often have a louder voice in policy discussions, allowing them to shape regulations in a way that minimises their burden while promoting environmental innovation. The fifth hypothesis thus proposes that:

H5: Large firms engaged in EI do not experience a significant differential impact from informational and regulatory barriers compared to those engaged in general innovation.

These hypotheses, summarised in Figure 1, collectively navigate the nuanced terrain of EI, highlighting the multifaceted barriers—from financial constraints to regulatory frameworks and informational deficits—that firms engaged in EI must overcome.

Figure 1 about here.

3. Method

This study's analysis is based on data from the Office for National Statistics (ONS) (2021) UK Innovation Survey (UKIS), which is a part of the European Community Innovation Survey. The sample framework is constructed using administrative data on employment and turnover from PAYE and VAT registered firms. The survey employs a complex stratified sampling method, considering factors such as firm size, sector, region for firms with ten or more employees in service and manufacturing sectors, and a census of firms with 250 or more employees. The survey comprises approximately 30 different questions, with slight variations across different years. To ensure consistency, the sample is limited to observations between 2009 and 2018.

This study focuses only on firms that are engaged in innovation. This approach restricts the sample of firms to only those engaged in innovation, and then separates firms that are motivated by environmental concerns. Because these firms are engaged in innovation, they are likely to have more experience and understanding of the barriers to innovation compared with non-innovators (D'este et. al., 2012).

First, the dependent variable was transformed to a binary variable, taking a value of 1 when the firm considers reducing environmental impacts as of high or medium importance in its decision to innovate in goods, services, and/or processes, and 0 otherwise. This transformation addresses the issue of magnitude within the variable's scale. Consistent with previous studies (e.g., Souto and Rodriguez, 2015), all barriers presented in the survey are included as independent variables. They are grouped as economic risks and other economic factors (economic risks, uncertain demand, lack of qualified personnel); financial barriers (innovation costs, finance costs, finance availability); regulatory barriers (UK and EU regulations); and informational deficits (lack of information on technology or markets). Additionally, controls are incorporated into the analysis, including logarithmic employment and revenue to account for firm size, as well as dummies to control for whether the firm operates locally (within 100 miles), nationally, within the EU, or globally. Regional dummies are also included to control broad regions, and a two-digit SIC 2007 classification is employed to capture sector differences. Definitions of variables can be found in Appendix A.

While the standard approach would involve fitting Probit regressions (e.g., in Horbach et al., 2013), this method fails to account for the covariance structure of repeated measures within enterprise clusters. Therefore, the analysis adopts the Generalized Estimating Equation (GEE) methodology, which provides consistent estimators of regression coefficients and their variances under weak assumptions about the correlation among observations of the same firm. Introduced by Liang and Zeger (1986) as an extension of Generalized Linear Models (GLM), GEE includes the random component of the model for each marginal response, with a common link and variance function. Unlike GLM, GEE accounts for the covariance structure of repeated measures.

To assess the robustness of the findings, the data is split into 70% train and 30% test samples, allowing for the estimation of accuracy, precision, sensitivity, F-Score, and specificity. Additionally, further sensitivity analysis is conducted using GEE Logit regression (see Supplementary Materials for details).

4. Results

There is an overall increase in firms engaged in EI, with a noticeable reduction in 2013-2014 (Figure 2). The line shows the fluctuation in the number of firms involved in innovation activities in four survey waves, while the bar chart illustrates the varying level of importance in reducing environmental impact when undertaking innovation activities. Approximately half of firms that innovated were engaged in EI, but this fluctuated from 49% in 2009-2010 to 59%

in 2017-2018. These trends were broadly uniform across product, service, and process innovations.

Figure 2 about here.

Without further controls, the initial results showed that more firms engaged in EI faced barriers to innovation than firms that rated reducing environmental impact as less or not important (Figure 3). The proportions varied from a relatively marginal 27% for staff shortage to firms engaged in EI being twice more likely to select both EU and UK regulations as high and medium important.

Figure 3 about here.

Hypothesis Testing

Hypothesis 1: Economic Risks and Other Economic Factors

H1 posits that firms engaged in EI are likely to encounter greater economic risks without showing significant differences in other economic factors compared to their non-EI counterparts. The regression coefficients for economic risks (0.13, $p < 0.01$) affirm that economic risks significantly increase the likelihood of facing challenges associated with EI. The positive and significant coefficient indicates a direct relationship between economic risks and engagement in EI, substantiating the hypothesis that EI is associated with increased economic risks.

However, variables representing other economic factors show no significant difference, suggesting that aside from the unique economic risks, firms engaged in EI do not differ significantly in terms of other economic barriers from those not involved in EI. This supports the premise of H1 that, despite the heightened economic risks, other economic metrics do not distinguish firms engaged in EI from their counterparts.

Hypothesis 2: Innovation Costs, Financial Availability, and the Cost of Finance

H2 explores the relationship between innovation costs, financial availability, and the economic risk's influence on the cost of finance for firms engaged in EI. The non-significant coefficients for innovation costs (-0.04 , $p > 0.05$) and finance availability (0.03 , $p > 0.05$) indicate that these factors do not differ markedly for firms engaged in EI compared to those that are not engaged in EI. In contrast, cost of finance shows a significant positive association (0.27 , $p < 0.01$), illustrating that the economic risk inherent in EI significantly impacts the cost of finance. This result corroborates H2, highlighting that while direct costs and availability of finance might not differ, the perceived economic risks associated with EI substantially elevate financing costs.

Hypothesis 3: Regulatory Barriers

H3 asserts that firms engaged in EI face greater regulatory barriers than those in general innovation. The significant positive coefficients for UK regulations (0.30 , $p < 0.01$) and EU regulations (0.26 , $p < 0.01$) highlight the substantial impact of regulatory frameworks on firms engaged in EI. These findings confirm that regulatory barriers are indeed more pronounced for firms engaged in EI, validating H3 and underscoring the critical role regulations play in shaping the EI landscape.

Hypothesis 4: Informational Deficits

H4 proposes that firms engaged in EI encounter significantly more substantial information deficits compared to firms engaged in general innovation. The regression coefficients for info on technology (0.21 , $p < 0.01$) and markets (0.13 , $p < 0.01$) provide strong evidence of the significant informational barriers faced by firms engaged in EI. These results affirm H4,

demonstrating that informational deficits, particularly regarding technology and market knowledge, are more acute for firms undertaking EI.

Table 1 about here.

Hypothesis 5: Large Firms vs SMEs

Further insights emerge from separate regression analyses conducted across different firm size categories in Table 2. While the broader patterns of informational deficits remained consistent across these groups, a nuanced picture developed upon isolating large firms. Separate regressions were performed for different size groups. Within the discourse of EI, the exploration of informational deficits across firms of varying sizes yields insightful distinctions. For SMEs, the regression coefficients for info on technology present a contrast between small (0.27, $p < 0.001$) and medium (0.23, $p < 0.001$) firms, underscoring the acute challenges they face in accessing technological information pertinent to EI. This trend starkly contrasts with larger firms, where the coefficient drops to 0.16 ($p < 0.05$), suggesting a mitigated, though still potentially present for some large firms, challenge.

Similarly, the information on markets coefficients for small (0.24, $p < 0.001$) and medium (0.15, $p < 0.01$) firms highlight significant barriers in understanding market dynamics related to EI. In comparison, large firms exhibit a coefficient of 0.07 ($p > 0.05$), indicating a non-significant impact. These comparative analyses affirm the hypothesis that informational deficits are more pronounced in SMEs undertaking EI, with large firms experiencing these barriers to a lesser extent potentially due to their resource advantages and broader network access.

The discussion extends to regulatory barriers, where disparities in the perception of EU regulations emerge as particularly telling. SMEs perceive these regulations as significant barriers to EI, with coefficients indicating strong significance for both small (0.28, $p < 0.001$) and medium (0.21, $p < 0.01$) firms. This perception starkly contrasts with large firms, which report a significantly higher coefficient of 0.47 ($p < 0.01$), revealing a unique challenge at the intersection of size and regulatory scope. This delineation is especially notable when compared to the relatively uniform perception of UK regulations across firm sizes, suggesting a nuanced landscape where the scale of regulatory frameworks intersects with firm size to influence the barriers to EI.

Table 2 about here.

5. Discussion

The exploration into the intersection of market failures and EI reveals a multifaceted terrain influenced by economic risks, regulatory landscapes, and informational deficits. By validating the hypotheses posited in this research, the study not only reinforces the theoretical constructs posited by market failure scholars such as Baumol & Oates (1988) and Oltra (2008) but also unveils the complex dynamics that underpin EI. Particularly, against the backdrop of the UK's unique pre-Brexit environment. The empirical insights garnered here significantly enrich the dialogue, offering critical, nuanced understandings that are pivotal for academics, industry stakeholders, and policymakers alike.

The confirmation of Hypothesis 1 illustrates that firms engaged in EI are significantly impacted by greater economic risks. This finding resonates with the theoretical underpinnings related to market failures, specifically the misalignment between the private returns and societal value of environmental goods, leading to underinvestment in EI. This study extends these theoretical frameworks by empirically demonstrating that beyond general economic barriers, firms pursuing EI are particularly challenged by heightened economic risks and

financial barriers. These increased financing costs potentially arise because of information asymmetry; thus, increasing the cost of finance and creating a market failure, which leads to underinvestment in EI (Jaffe, Newell, and Stavins 2005). These findings support the notion posited by Verdolini et al. (2021) and Pellegrino and Savona (2017) concerning the unique financing dynamics of EI projects, underscoring the need for policy interventions tailored to mitigate these identified market inefficiencies.

The investigation into regulatory challenges and informational deficits also sheds light on the significant barriers impeding EI. This study's findings highlight the complexity of the regulatory environment in the pre-Brexit UK, emphasising the substantial compliance costs and administrative burdens that amplify the obstacles faced by firms dedicated to environmental sustainability. This aligns with ongoing discussions in the literature about the intricate relationship between environmental regulation, corporate environmental responsibility, and their collective impact on innovation (Bergek, Hellsmark, and Karltorp 2023).

Regulatory frameworks, initially crafted to protect public interests and promote sustainable practices, often inadvertently introduce significant compliance costs and administrative burdens on firms engaged in EI (Narassimhan, Myslikova, and Gallagher 2024; Weitzman, 1974). It therefore becomes paramount that regulations are thoughtfully structured within a comprehensive suite of policies aimed at nurturing the growth and spread of EI, rather than stifling it (Jaffe, Newell, and Stavins 2005, p. 165). The academic consensus advocates for regulatory approaches that incentivise EI, arguing these to be substantially more effective than the traditional prescriptive command-and-control strategies (Jaffe, Newell, and Stavins 2005; Requate, 2005).

Such incentive-driven regulations could serve as catalysts for EI, potentially reconciling the disparate findings in existing literature regarding regulatory impacts on EI. This dialogue includes the notable Porter Hypothesis, which contends that environmental regulations can indeed propel innovation (Porter, 1991). According to Porter, by implementing stringent yet achievable environmental standards, governments can motivate firms not only to comply with these regulations but also to leverage innovation as a means to enhance their competitiveness and efficiency. This theoretical perspective contrasts with this study's findings, suggesting a nuanced exploration of the conditions under which regulations can effectively stimulate innovation in the environmental sector.

Furthermore, this research highlights the critical role of informational deficits in hindering EI, especially in terms of accessing up-to-date information on environmental technologies and market trends. This challenge is compounded by the rapid pace of change in both technology and regulatory requirements, leading to cautious investment decisions. This finding is supported by Akerlof (1970), who discussed the impact of information asymmetry on market transactions and is further evidenced in the context of EI by Horbach et al. (2013) and Pinkse et al. (2024). These authors have underscored the intensive information and knowledge requirements inherent in EI, necessitating collaborations and knowledge exchange to bridge these gaps.

Furthermore, this exploration of EI barriers across firms of varying sizes contributes to filling a critical research gap, particularly in the context of SMEs, in light to their significant economic contributions and environmental impact (Pinget, Bocquet, and Mothe 2015; Passaro et al. 2023; Calogirou et al. 2010). This study confirms that SMEs face distinct challenges, notably more pronounced informational and regulatory obstacles compared to larger counterparts. This disparity is often attributed to SMEs' limited internal R&D capabilities, smaller external networks, and reduced absorptive capacity, which exacerbates their struggle with navigating environmental legislation and compliance processes (D'Este et al., 2012;

Calogirou et al., 2010). These findings underscore the urgent need for management strategies and policy interventions to be tailored to accommodate the diverse requirements and constraints associated with firm size. Implementing such differentiated approaches is crucial for fostering a supportive ecosystem that enables effective EI engagement across the entire spectrum of firm sizes, a consideration currently overlooked in the design of environmental regulations.

Contrasting the findings presented in this paper with earlier European research (e.g., Souto and Rodriguez, 2015; Stucki, 2019), which identified finance availability, staff shortages, monopolies, and uncertain demand as key barriers, this study reveals a notable divergence. Indeed, this study suggests that in the UK context, these factors do not disproportionately affect firms engaged in EI, pointing to a distinct set of challenges centred around regulatory burdens, financial barriers, and informational deficits. This divergence underscores the geographical and contextual nuances in the barriers to EI leading to the Brexit referendum, highlighting the importance of tailored policy interventions and market mechanisms that address the specific challenges encountered in different regions.

6. Conclusions

This study contributes to a deeper understanding of the unique market dynamics and challenges associated with EI. It delineates the critical role of regulatory frameworks, financial considerations, and information asymmetry in shaping the landscape of EI, particularly in the UK context. The findings reveal that firms engaged in EI encounter a distinct set of barriers, with regulatory challenges, informational deficits, and financial constraints being more prominent compared to firms engaged in general innovation.

At first glance, it may seem that firms in the post-Brexit UK, now external to the European Union's single market, would encounter fewer informational and regulatory barriers because of their liberation from the EU single market and regulations. This detachment suggests a potential decrease in specific constraints. Nonetheless, this new independence ushers in a set of fresh challenges. Absent from the EU's regulatory ambit, these entities must adapt to a shifting framework of UK-specific regulations intended to either mirror or diverge from EU norms, alongside the intricacies involved in establishing new trade agreements and aligning with global environmental standards without the direct mediation of EU protocols (Matikonis and Garavan 2023). Consequently, while the immediate burdens of EU regulatory compliance may lessen, UK firms are faced with an array of alternative challenges. These necessitate sophisticated strategies for understanding and integrating into a radically altered regulatory and trade environment, underscoring the need for dynamic approaches to maintain and progress their environmental innovation initiatives in a landscape transformed by Brexit.

The evidence presented in this study, alongside the insights drawn from the broader academic literature (Bergek, Hellsmark, and Karltorp 2023; Horbach, Oltra, and Belin 2013; Sala and Silva 2013; Pinkse, Demirel, and Marino 2024; Arvanitis et al. 2017), highlights the need for targeted policy interventions and market mechanisms to facilitate EI. Implementing specialised support programs, fostering regulatory environments that incentivise sustainable EI, and enhancing information sharing and collaboration among stakeholders are critical steps towards mitigating the challenges identified. This aligns with the recommendations of Verdolini et al. (2021), Bergek et al. (2023) and other scholars who have emphasised the importance of policy and market reforms in promoting sustainable business practices and addressing the impacts of climate change.

Limitations and Future Directions

This study, while providing insightful findings on the barriers to EI within the UK context, has limitations that stem from its reliance on secondary data. The use of existing datasets, although beneficial for broad analyses, inherently restricts the depth of insight that can be gained about the nuanced experiences and perceptions of firms engaged in EI. Such data may not fully capture the dynamic and evolving nature of the regulatory, financial, and informational landscapes affecting EI. Furthermore, the secondary nature of the data limits the ability to tailor questions specifically designed to probe the unique challenges faced by EI firms, potentially overlooking sector-specific barriers or innovative strategies employed to overcome these obstacles.

Given these limitations, future research could greatly benefit from incorporating qualitative studies, such as in-depth interviews or case studies, to complement the findings from secondary data analysis. A qualitative approach would allow for a richer, more detailed exploration of the complexities surrounding EI, offering nuanced insights into the strategic decisions of firms, their perceptions of regulatory and financial challenges, and the specific informational needs related to environmental technologies and market trends. Such studies could also explore the impact of geographic and sectoral contexts on the barriers to EI, providing a more comprehensive understanding of the factors that facilitate or hinder sustainable innovation.

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Appendices

Appendix A: Descriptions of Independent and Control Variables

Variable	Description
Economic risks*	A dummy taking the value of 1 when excessive perceived economic risks were classed as high or medium important in constraining innovation activities and 0 otherwise.
Innovation costs*	A dummy taking the value of 1 when high direct innovation costs were classed as high or medium important in constraining innovation activities and 0 otherwise.
Cost of finance*	A dummy taking the value of 1 when cost of finance was classed as high or medium important in constraining innovation activities and 0 otherwise.
Finance availability*	A dummy taking the value of 1 when finance availability was classed as high or medium important in constraining innovation activities and 0 otherwise.
Qualified personnel*	A dummy taking the value of 1 when the lack of qualified personnel was classed as high or medium important in constraining innovation activities and 0 otherwise.
Information on technology*	A dummy taking the value of 1 when lack of information on technology was classed as high or medium important in constraining innovation activities and 0 otherwise.
Information on markets*	A dummy taking the value of 1 when lack of information on markets was classed as high or medium important in constraining innovation activities and 0 otherwise.
Monopolies*	A dummy taking the value of 1 when market dominated by established firms was classed as high or medium important in constraining innovation activities and 0 otherwise.
Uncertain demand*	A dummy taking the value of 1 when uncertain demand for innovative goods or services was classed as high or medium important in constraining innovation activities and 0 otherwise.
UK government regulations*	A dummy taking the value of 1 when UK government regulations were classed as high or medium important in constraining innovation activities and 0 otherwise.
EU regulations*	A dummy taking the value of 1 when UK regulations were classed as high or medium important in constraining innovation activities and 0 otherwise.
Operating area	Four dummy variables taking the value of 1 when firms are operating locally, nationally, EU or globally and 0 otherwise.
Logarithmic Employment *	Number of employees

Logarithmic Revenue or Turnover*	Income that a firm generates through trading its goods and services in thousand £
Region	Wales, Scotland, North East, North West, Yorkshire and Humberside, East of England, East Midlands, West Midlands, London, South East and South West
Sector	Two digit Sic-2007 classification.

* denotes derived variables.

Appendix B: Descriptive Statistics

	High/medium			Low/no		
	N	Mean	St. Dev.	N	Mean	St. Dev.
Economic risks	5,031	0.58	0.49	4,770	0.42	0.49
Innovation costs	5,031	0.65	0.48	4,770	0.51	0.5
Cost of finance	5,031	0.52	0.5	4,770	0.33	0.47
Availability of finance	5,031	0.48	0.5	4,770	0.33	0.47
Personnel	5,031	0.53	0.5	4,770	0.42	0.49
Info on technology	5,031	0.38	0.48	4,770	0.21	0.4
Info on markets	5,031	0.37	0.48	4,770	0.21	0.41
Monopolies	5,031	0.46	0.5	4,770	0.33	0.47
Uncertain demand	5,031	0.52	0.5	4,770	0.38	0.49
UK regulations	5,031	0.42	0.49	4,770	0.21	0.41
EU regulations	5,031	0.39	0.49	4,770	0.18	0.38
Innovated in product	5,031	0.54	0.5	4,770	0.43	0.5
Innovated in service	5,031	0.53	0.5	4,770	0.56	0.5
Innovated in process	5,031	0.61	0.49	4,770	0.54	0.5
Turnover	5,031	75,656	464,688	4,770	41,213	323,773
Employment	5,031	438	3,223	4,770	215	985
Turnover growth	4,567	7.55	167.27	4,452	7.53	79.76
Employment growth	4,601	1.39	2.42	4,509	1.35	1.6
Operating within 100 miles	5,031	0.49	0.5	4,770	0.48	0.5
Operating nationally	5,031	0.72	0.45	4,770	0.73	0.44
Operating within EU	5,031	0.46	0.5	4,770	0.43	0.5
Operating globally	5,031	0.38	0.48	4,770	0.37	0.48

Data limited to 2017-2018 to avoid bias toward larger firms given the sampling.

Appendix C: Number of observations per region

Region	No/low	Medium/high
North East (AA)	419	368
North West (BA, BB)	885	780
Yorkshire and Humberside (DC)	707	599
East Midlands (ED)	646	586
West Midlands (FE)	716	671
East of England (GF, GG)	808	666
London (HH)	1336	1037
South East (JG)	1164	978
South West (KJ)	715	599
Wales (WW)	510	477

Scotland (XX)	853	823
Northern Ireland (YY)	339	314

Figures and Tables

Figure 1 Conceptual framework.

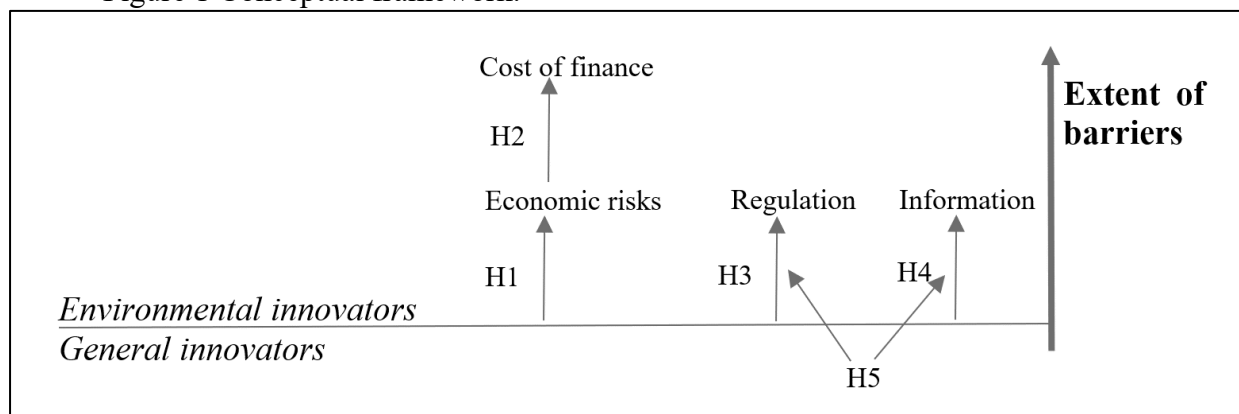


Figure 2 Importance of Reducing Environmental Impact among Innovating Firms between 2009 and 2018.

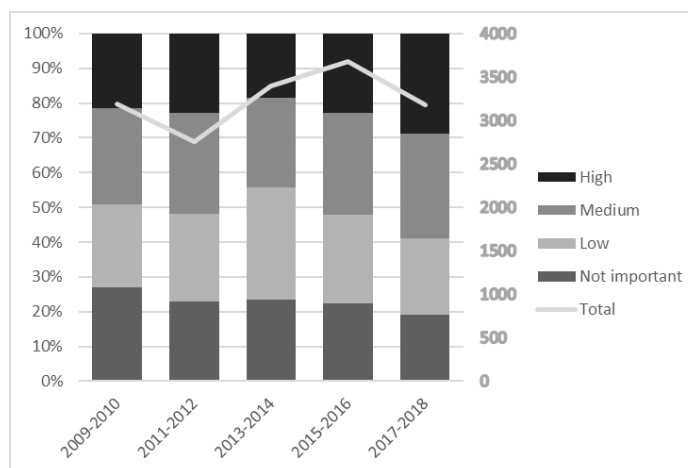
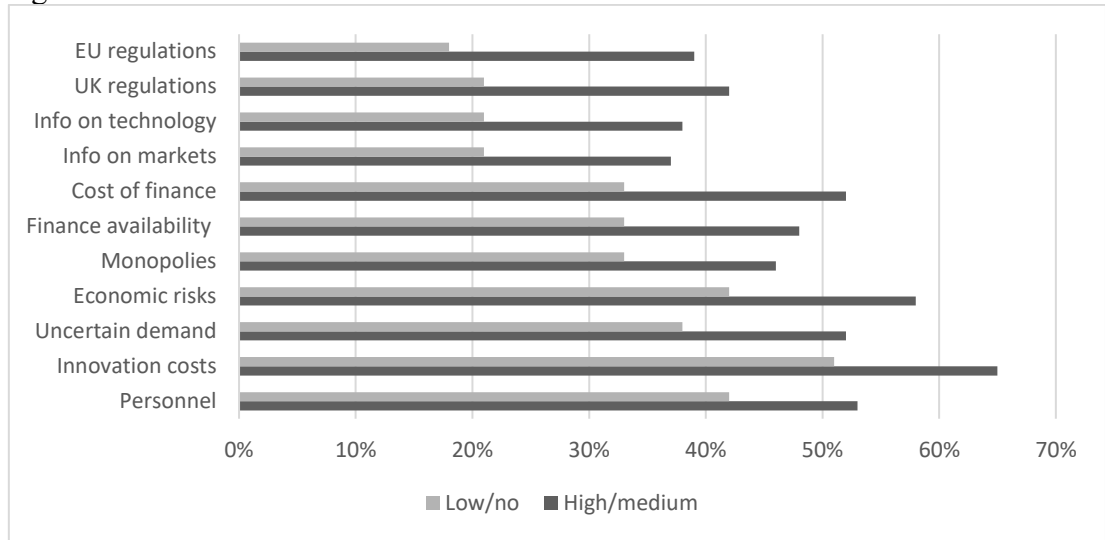


Figure 3 % of Firms with Barriers to Innovation Activities 2017-2018.



Descriptive statistics of these variables and controls are available in Appendix B and C.

Table 1: Output of GEE Probit Regression

		Coef.	Std.err	Wald	
Category	(Intercept)	-0.23	0.14	2.66	
Economic barriers	Economic risks	0.13	0.04	12.31	***
	Personnel	-0.01	0.04	0.10	
	Uncertain demand	0.03	0.04	0.78	
	Monopolies	0.03	0.04	0.62	
Financing barriers	Innovation costs	-0.04	0.04	1.03	
	Cost of finance	0.27	0.04	37.56	***
	Finance availability	0.03	0.04	0.61	
Informational deficits	Info on technology	0.21	0.04	26.01	***
	Info on markets	0.13	0.04	10.32	***
Regulatory barriers	UK regulations	0.30	0.05	37.34	***
	EU regulations	0.26	0.05	28.51	***
	Operating within 100 miles	-0.10	0.03	8.97	***
	Operating nationally	-0.10	0.04	5.75	**
	Operating within EU	0.11	0.04	5.83	**
	Operating globally	-0.04	0.04	1.00	
	Log turnover	0.00	0.01	0.01	
	Log employment	0.05	0.01	15.83	***
	No of clusters (Std.err)	7144 (0.03)			
	Accuracy	0.66			
	Precision	0.69			
	Sensitivity	0.67			
	F-Score	0.68			
	Specificity	0.66			

Significance levels: *** for <0.01, ** for <0.05. Data Limited to Firms Innovating in Service, Product and Process. Region and SIC dummies were included but not reported. Full output is available in the supplementary materials.

Table 2: GEE Probit Models Separated by the Size of Firm

	Employment ≤ 50				50 < Employment ≤ 250				Employment >250		
	Estimate	Std.err	Wald		Estimate	Std.err	Wald		Estimate	Std.err	Wald
(Intercept)	-0.24	0.26	0.85		0.26	0.36	0.52		-1.23	0.40	9.37 ***
Economic risks	0.07	0.06	1.59		0.19	0.06	8.98 ***		0.23	0.08	7.33 **
Innovation costs	0.02	0.06	0.11		-0.07	0.07	1.13		-0.09	0.09	1.04
Cost of finance	0.28	0.07	18.53 ***		0.34	0.08	19.09 ***		0.23	0.11	4.83 **
Finance availability	0.06	0.06	0.89		-0.11	0.08	1.97		0.06	0.10	0.32
Personnel	-0.04	0.05	0.55		-0.01	0.06	0.02		0.05	0.09	0.29
Info on technology	0.27	0.06	18.01 ***		0.23	0.07	10.90 ***		0.16	0.10	2.45
Info on markets	0.24	0.06	14.97 ***		0.15	0.07	4.66 **		0.07	0.11	0.41
Monopolies	0.00	0.06	0.00		0.02	0.06	0.09		0.13	0.09	2.15
Uncertain demand	-0.04	0.06	0.51		-0.01	0.06	0.01		0.03	0.09	0.10
UK regulations	0.24	0.07	11.67 ***		0.29	0.09	11.96 ***		0.19	0.13	2.22
EU regulations	0.28	0.07	16.18 ***		0.21	0.08	6.54 **		0.47	0.14	11.61 ***
Operating within 100 miles	-0.13	0.05	5.93 ***		-0.06	0.06	1.26		-0.03	0.08	0.13
Operating nationally	-0.04	0.06	0.48		-0.07	0.07	0.79		-0.36	0.10	12.10 ***
Operating within EU	0.05	0.07	0.59		0.13	0.07	2.93 *		0.04	0.10	0.11
Operating globally	-0.09	0.06	2.12		-0.06	0.07	0.93		0.06	0.10	0.38
Log turnover	0.00	0.01	0.01		-0.01	0.02	0.19		0.02	0.02	1.13
Log employment	-0.02	0.02	0.97		-0.02	0.06	0.17		0.19	0.05	18.21 ***
No of clusters (Std.err)	3054(0.09)				2661(0.09)				1523(0.19)		
Accuracy	0.66				0.66				0.65		
Precision	0.72				0.72				0.75		
Sensitivity	0.68				0.68				0.69		
F-Score	0.70				0.70				0.72		
Specificity	0.64				0.64				0.57		

Significance levels: *** for <0.01, ** for <0.05, * for <0.1. Data Limited to Firms Innovating in Service, Product and Process. Region and SIC dummies were included but not reported.