sustainability

Article

Enabling Green Innovations for the Circular Economy: What Factors Matter?

Iulia Siedschlag [1,2,*], Stefano Meneto [1,2] and Manuel Tong Koecklin [1,2]

[1] Economic and Social Research Institute, D02 K138 Dublin, Ireland
[2] Department of Economics, Trinity College Dublin, D02 PN40 Dublin, Ireland
* Correspondence: iulia.siedschlag@esri.ie

Abstract: Recent economic theory and international evidence have established that innovations with environmental benefits (green innovations) are crucially important to increase resource efficiency and accelerate the transition to a circular economy. However, robust empirical evidence on what factors drive green innovations at firm-level is limited and inconclusive. To help fill this evidence gap, we designed and used a unified econometric framework to quantify the impact of a comprehensive set of factors on the propensity of firms to introduce innovations with environmental benefits. Such factors include environmental regulations, innovation-inputs, firm-specific characteristics, spillovers from other green innovators, public funding, and co-operation for innovation activities. We distinguished and examined innovations with environmental benefits obtained within the firm and innovations with environmental benefits obtained during the consumption of goods or services by the end user. In addition to average effects across all firms, we also uncovered specific effects for different groups of firms and industries. The results indicate that environmental regulations, in-house R&D, and acquisition of capital assets are important factors that enable firms to introduce green innovations. These results have implications for designing policies aiming at enabling more firms to introduce green innovations and thus accelerate the transition to a circular economy and a more sustainable long-term growth.

Keywords: green innovations; circular economy and sustainability; firm behaviour; environmental regulations

check for updates

Citation: Siedschlag, I.; Meneto, S.; Tong Koecklin, M. Enabling Green Innovations for the Circular Economy: What Factors Matter? *Sustainability* **2022**, *14*, 12314. https://doi.org/10.3390/su141912314

Academic Editors: Marina De Pádua Pieroni, Mariia Kravchenko, Daniela C. A. Pigosso and Tim C. McAloone

Received: 1 August 2022
Accepted: 23 September 2022
Published: 28 September 2022

1. Introduction

The circular economy model has emerged as an alternative to the neoclassical linear economic model underlined by the "take-made-dispose" which has had negative implications for the environment [1,2]. The circular economy is seen as a regenerative system that minimizes the entry and waste of resources, emissions, and energy consumption [3]. A large body of economic theory and recent international evidence have established that innovations with environmental benefits (green innovations) are key to increasing resource efficiency and the development of a circular economy [4–8]. While it is widely acknowledged that green innovations are essential to a sustainable development, robust empirical evidence on what factors influence the propensity of firms to introduce innovations aimed at increasing resource efficiency and a circular business model is limited and inconclusive. Most of the existing literature on innovations linked to the circular economy is based on case studies [9,10]. Given well-known negative externalities associated with environmental challenges and specific market failures, it is also increasingly accepted that government actions are needed to foster green innovations [11–19]. Understanding what drives the propensity of firms to introduce innovations with environmental benefits could improve the knowledge base of policies aiming to incentivise firms to invest in green innovations and foster a circular economy and sustainable development.

Green innovations include new or modified products, processes, practices, and systems, that aim at reducing or removing the environmental damaging effects of economic activity [20,21]. While much of the recent literature is focused on factors underlying inventions with environmental benefits measured with patents, the empirical literature on the factors underlying the introduction of green innovations in a broader sense is still relatively small.

This article examines factors that influence the propensity of firms to introduce green innovations. Using micro data from Ireland, we analyse a broad range of factors, including environmental regulations, innovation inputs, firm-specific characteristics, spillovers from other firms with green innovations in the same industry, co-operation for innovation activities, and public funding. We first consider all innovations with environmental benefits. Second, we distinguish and separately analyse innovations with environmental benefits obtained within the firm and innovations with environmental benefits obtained during the consumption or use of a good or service by the end user. In addition to average effects across all firms, to account for potentially different firm behaviour, we separately analyse manufacturing and services firms and indigenous and foreign-owned firms.

Our contribution to the literature is novel in three ways. First, we design and use a unified econometric framework to examine a comprehensive set of factors that influence the engagement of firms in green innovation. Second, we allow for a heterogeneous innovation behaviour across different groups of firms and industries. Third, we provide new evidence on the role of spillovers from other green innovators in the same industry on the propensity of firms to introduce green innovations.

The key results of this research indicate that environmental regulations, in-house research and development (R&D) activity, and acquisition of capital assets are major drivers of green innovations. Larger firms are more likely to introduce green innovations. This result holds for all firms as well as all groups of firms analysed with the exception of firms in services. The propensity of service firms to introduce green innovations increases with the share of green innovators in the same industry. Such a spillover effect is not identified in the case of the other groups of firms. Relative to foreign-owned firms, indigenous firms are more likely to introduce green innovations with benefits for the end user. This result holds across all firms as well as for manufacturing and services firms. These results have implications for designing policies aiming at enabling more firms to introduce green innovations and thus accelerate the transition to a circular economy and a more sustainable long-term growth.

The remainder of this article is organised as follows. Section 2 discusses existing international evidence on the propensity of firms to introduce green innovations, and on that basis, we identify evidence gaps and propose a set of testable research hypotheses. Section 3 presents the data and empirical methodology. Section 4 discusses the empirical results. Finally, Section 5 concludes.

2. Literature Review and Research Hypotheses

Existing international evidence based on firm-level analysis has identified several factors that influence the propensity of firms to introduce green innovations, including environmental regulations, internal R&D and technological capabilities, access to external knowledge, firm specific characteristics, exposure to competition in international markets, spillovers from other green innovators, and public funding. On the basis of this evidence, we identify research gaps to be filled and propose a set of testable research hypotheses.

2.1. Environmental Regulations

The hypothesis that well-designed environmental regulations boost green innovations has been put forward by Porter [22] and developed theoretically by Acemoglu et al. [23]. Following on from this literature, a large number of firm-level empirical studies have found that environmental regulations, including government legislation such as laws, acts, and directives, are an important driver for the introduction of green innovations [24,25]. However, a limited number of studies have found that the effect of environmental regulations on the propensity of firms to introduce green innovations could be negative in specific sectors or with respect to specific innovation types.

Cross-country studies based on firm-level data provide useful evidence highlighting similarities across countries and innovation types as well unique features on the effects of environmental regulations on the introduction of green innovations. Fabrizi, Guarini, and Meliciani [26] analyse patent data from European countries and provide evidence indicating that market-based regulations foster environmental innovations. Further, they show that the effect of regulations on green innovations can be enhanced by innovation policies that incentivise and enable participation in green European research networks. Using data from 22 EU countries, (Belgium, Bulgaria, Cyprus, Croatia, Czech Republic, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia and Sweden) Crespi, Ghisetti, and Quatraro [27] uncover the effect of announced future environmental regulations as a driver of green innovations in the area of improving recycling after sales use, carbon dioxide emissions, material use, and different pollution after sales use. A study by Horbach [28] on the determinants of green innovations in 19 EU countries (Bulgaria, Cyprus, Czech Republic, Germany, Estonia, Finland, France, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Portugal, Romania, Sweden, and Slovakia) finds that environmental regulations play a more important role for the introduction of green innovations with environmental impacts on air, soil, and water than in sectors that deal with energy and material savings. This result is more pronounced for Eastern European countries than in Western Europe. A study by Garrone, Grilli, and Mrkajic [29] focuses on the role of regulatory pressure on firms' propensity to adopt energy efficiency innovations in 9 EU countries (Bulgaria, Czech Republic, Germany, Hungary, Italy, Lithuania, Portugal, Romania, and Slovakia). The authors show that environmental regulations promote the creation of product and process innovation with green features. Stucki et al. [30] analyse firms in Austria, Germany, and Switzerland and find that, on average, regulations have a negative effect on the introduction of green innovations. In particular, the authors find that process innovations are less impacted by regulation than product innovations. The evidence indicates a positive effect of environmental regulations on technological leaders only, as opposed to a negative effect on laggard firms. Stojčić [31] find evidence from central European countries showing that a combination of regulations, procurement, financial, and private incentives increased the likelihood of environmental innovations with social benefits.

Further evidence on the relationship between environmental regulations and firms' propensity to introduce green innovations is provided by country-level analyses. We first discuss evidence from large countries and we then turn to evidence from small open economies. Horbach, Oltra, and Belin [20] find that environmental regulations played a major role in the introduction of green innovations in France and Germany. In the case of Germany, Horbach [32] investigates the determinants of green innovations where the importance of compliance with environmental regulatory measures is used as an indicator for environmental policy over the period 1993–2004. The author finds a statistically significant and positive effect of environmental regulations, both present and expected, on the introduction of green innovations. Additionally, in the case of Germany, Rennings and Rammer [33] investigate drivers of green innovations at a disaggregated sectoral level and conclude that the effect of environmental regulations on innovation success varies by the field of environmental policy. Among their results, and partially in contrast to Horbach [32], they find a negative impact of regulations on innovation success in the water management and power generation sectors. On the other hand, Horbach, Rammer, and Rennings [34] find positive and statistically significant effects of present and expected regulations on reducing firms' emissions of noise, water, and air. These findings are similar to those of Ketata, Sofka, and Grimpe [35]. Borghesi, Cainelli, and Mazzanti [36] find that the EU ETS is negatively associated with green innovations. The authors argue that this result might be related to pre-emptive behaviour from early moving firms. In contrast to these findings, Peñasco, del Río, and Romero-Jordán [37] conclude that the EU ETS played a significant and positive role on the introduction of green innovations in Spain. A study by Leoncini, Montresor, and Rentocchini [38] focuses on drivers of innovations dealing with reductions of CO_2 from 2006 and 2010. The authors find a highly significant and positive effect of environmental regulations on the reduction of a firm's footprint. In the case of the UK, Ramanathan et al. [39] find that environmental regulations have a negative effect on green innovation in the short run, similar to the results of Borghesi, Cainelli, and Mazzanti [36]. Horbach and Rammer [40] examine the role played in the process of diffusion of green technologies and find that expected environmental regulations played a more influential role for renewable energy innovations, as opposed to current regulations.

Cui et al. [41] find that environmental regulations in China have fostered, in particular, radical green innovations. The effect is stronger in industries with a higher pollution intensity. Further evidence from China provided by Hu, Pan, and Huang [42] indicates that the carbon emission trading scheme had positive effects on the quantity and quality of innovation. They find that these positive effects are limited to enterprises which are state-owned enterprises, large, and located in the east. Li et al. 2022 [19] finds that environmental regulations had a non-linear and small effect on the green innovation behaviour of firms in the construction sector in China. They explain this result by the improvement of the green performance of the construction sector over time requiring less environmental regulations.

Empirical studies on the effects of environmental regulation on the propensity of firms to introduce green innovations in small open economies find similar results to those for large economies such as Germany and Italy. Using data from Ireland, Doran and Ryan [43] examine the factors driving green innovations, with particular attention to the role of government regulations to incentivise the introduction of these innovations. Their results indicate that the propensity of firms to introduce green innovations is influenced by current and expected environmental regulations. Veugelers [44] found similar results in the case of Belgium. In addition, her analysis uncovers that developers of green innovations are more responsive to policy intervention than adopters of green innovations. Van Leeuwen and Mohnen [45] add to the literature by identifying both direct and indirect effects of environmental regulations on the introduction of green innovations in the Netherlands. In addition, the authors find complementary effects of introducing pollution-reducing and resource-saving green innovations. Using data from South Korea, Castellacci and Lie [46] find that environmental policy played an important role in firms' green innovations in the waste and pollution-reducing sectors.

Taken together, the evidence discussed above suggests the following testable hypothesis:

Hypothesis H1. *Environmental regulations foster the introduction of green innovations.*

2.2. Innovation Inputs

Another important factor for the introduction of green innovations are innovation inputs, such as investment in research and development (R&D), co-operation with public and private entities, and acquisition of capital assets and of external knowledge.

Horbach [32] finds that improvements to German firms' technological capabilities increase the likelihood of introducing green innovations. Moreover, from the study of Horbach [47], it emerges that external knowledge sources, such as regional proximity to research centres and universities, increases the likelihood of adopting green innovations, compared with other innovations. Using data from Italy, Cainelli, Mazzanti, and Montresor [48] find that foreign ownership impacts the likelihood of introducing green innovations conditional on a firm's cooperation with its own suppliers. Borghesi, Cainelli, and Mazzanti [36] uncover the importance of acquisition of external knowledge as the most relevant driver of green innovation in Italy. Using a panel dataset of Italian firms from 2005 to 2010, Cainelli, De Marchi, and Grandinetti [49] conclude that R&D activity, cooperation with suppliers and universities, acquisition of external knowledge, and equipment are more relevant for green innovations than other innovations.

Duque-Grisales et al. 2020 [14] highlight the importance of investment in R&D for leveraging green innovation as a strategic resource. Awan, Arnold, and Gölgeci [50], and Awan, Nauman, and Sroufe [51] point to the role of internal competencies and the role of knowledge acquisition capabilities within the firm to enhance green innovations.

Peñasco, del Río, and Romero-Jordán [37] show that in Spain, firms that cooperate with national and international partners increase their likelihood of introducing green innovations and that the effect of cooperation with international partners is larger than the effect of cooperation with national partners. A study by Badillo and Moreno [52] using data on Spanish firms between 2004 and 2011 reinforce the findings of Peñasco et al. [37]. Kunapatarawong and Martínez-Ros [53] conclude that as firms increase in size, there is a shift from internal to external knowledge when developing green innovations. Doran and Ryan [43] find that strengthening the cooperation between Ireland's firms in the supply chain increases the likelihood of developing green innovations. Castellacci and Lie [46] show that green innovations by firms in South Korea in the carbon dioxide and waste reducing sectors are mainly driven by internal R&D capability and strong links to public research institutes and universities.

In a cross-country study (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom), Jaumotte and Pain [54] find evidence indicating that past R&D and patenting activity as well as greater co-operation between firms and with government research organisations and universities are important determinants of green innovations. Horbach [28] analyses data from 19 European countries (Bulgaria, Cyprus, Czech Republic, Germany, Estonia, Finland, France, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Portugal, Romania, Sweden, and Slovakia) and concludes that internal R&D plays a crucial role for innovations with environmental benefits in the area of material and energy savings.

Kiefer et al. [55] find that internal factors such as physical resources, competences and capacities, technology, involvement in green supply chains, internal financial resources, and corporate culture favourable to green innovations are important drivers of innovations with environmental benefits. Junaid et al. 2022 [56] provide further evidence from Pakistan on the role of sustainable supply chain integration in fostering green innovations.

As suggested by previous evidence [57–59], firms' capacity to use innovation inputs such as internal R&D, technological capabilities, and access to external knowledge is influenced by the legal system in place for protecting information and new knowledge such as the system of patents, licenses, know-how, and trade secrets. As shown by Agostini et al. [57], the geographical scope of the protection in terms of the number of jurisdictions where the protection is extended plays an important role in that regard, particularly for the performance of SMEs. Further evidence provided by Hsueh and Chen [58] indicate that SMEs patent strategies are correlated with firm size and R&D expenditures. Mingaleva and Mirskikh [59] highlight the role of an appropriate legal system for intellectual property protection in enabling and fostering SME innovations.

On the basis of this evidence, we propose to test the following research hypothesis:

Hypothesis H2. *Innovation inputs such as internal R&D, technological capabilities, and access to external knowledge enhance the introduction of green innovations.*

2.3. Firm-Specific Factors

International evidence indicates that firm-specific and sector-specific factors play a significant role in the decision of firms to introduce green innovations. Horbach [47] finds that energy-intensive sectors, such as mining and chemicals, are more likely to adopt green innovations. Ketata, Sofka, and Grimpe [35] show that in the case of firms in Germany, investment in employee training has a greater impact than R&D expenditures for the adoption of green innovations. Furthermore, in a study of the Emilia Romagna region in Italy by Cainelli, Mazzanti, and Montresor [48], no evidence is found with respect to foreign ownership of a firm as a determinant of green innovation. Borghesi, Cainelli, and Mazzanti [36] show that a significant determinant of green innovation is the intensity of energy expenditures of a given firm, arguing that the cost saving motive might be the underlying driver of green innovation. Wang et al. [60] provide evidence showing that publicly traded companies with a multi-stakeholder ownership structure have a higher level of green innovation.

Antonioli and Mazzanti [61] conclude that cooperative industrial relations, measured as union involvement of a particular firm in Italy, increase the likelihood of introducing green innovations. Antonioli, Borghesi, and Mazzanti [62] show that both training activities and the geographical position of a given firm in Italy increase the likelihood of introducing green innovations.

In a study of firms in Croatia, Aralica, Račić, and Radić [63] find that the likelihood of introducing green innovations increases with firm size.

Jaumotte and Pain [54] investigate the determinants of green innovation in a number of European countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom) and find that qualified personnel had a positive and significant effect on the introduction of green innovation. In a study of firms from 19 European countries (Bulgaria, Cyprus, Czech Republic, Germany, Estonia, Finland, France, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Portugal, Romania, Sweden, and Slovakia), using a panel dataset from 2004 to 2011, Badillo and Moreno [40] and Meirun, Makhloufi, and Ghozali Hassan [64] find that a firm's absorptive capacity is an important determinant of the likelihood of green innovations. Albort-Morant et al. [65] provide further evidence from the automotive components manufacturing in Spain on the positive relationship between absorptive capacity and green product and process innovations.

Skordoulis et al. [66] analyse data collected with a structured questionnaire using a range of statistical models and provide novel evidence showing a positive relationship between green entrepreneurship and green innovations. Further, they find that firms' strategies condition the relationships between green entrepreneurship, green innovations, and competitive advantage. Several studies have examined the role of leadership and entrepreneurship in fostering green innovations. Arici and Uysal 2022 [67] provide a systematic review of recent evidence from the service industries. Fang et al. 2022 [68] provide evidence from China on the role of entrepreneurship as a driver of green innovations.

Van der Waal et al. 2021 [69] provide evidence showing that multinational enterprises (MNEs) make an important contribution to sustainable development in terms of green innovations.

Taken together, the evidence discussed above suggests the following testable hypothesis:

Hypothesis H3. *Firm-specific factors, such as firm size, ownership, leadership, entrepreneurship, and absorptive capacity, enhance the introduction of green innovations.*

2.4. Exposure to International Competition

Leoncini, Montresor, and Rentocchini [38] show that the international orientation (measured as the ratio of export sales to total sales) of a firm acts as a determinant for the adoption of green innovations. Horbach [32] finds that German firms in the electrical machinery and motor vehicles industry, characterised by high export shares and thus exposed to international competition, are more likely to introduce green innovations than other firms. Horbach [47] and Horbach, Rammer, and Rennings [34] find evidence showing that the prospect of entrance of new firms acts as a determinant of green innovations for German firms. From a study by Horbach and Rammer [40], a positive correlation is found between higher international competition and the likelihood of introducing renewable energy innovations. On the other hand, Ziegler [70] finds no statistically significant effect of international competition on the introduction of green innovations in Germany. Horbach [28] shows that exporting does not play a crucial role for the introduction of green innovations. Stucki et al. [30] find that for firms in Austria, Germany, or Switzerland, export intensity has no impact on the likelihood of introducing green innovations.

A study by De Marchi [71] on firms in Spain finds a negative but statistically not significant effect of exports on the probability of introducing green innovations, suggesting that local markets may be more important for green innovations than for other types of innovations. Peñasco, del Río, and Romero-Jordán [37] corroborate the results of De Marchi [71] by also providing evidence that the outcome does not change whether the export market is European or extra European. Costa-Campi, García-Quevedo, and Martínez-Ros [72] show that firms in Spain that are more competitive and that have a greater international market are more likely to introduce green innovations.

The following hypothesis derived from the previous evidence can be tested:

Hypothesis H4. *Exposure to competition in international markets boosts the propensity of firms to introduce green innovations.*

2.5. Spillovers from Other Green Innovators

Spillovers from other innovators and/or foreign affiliates play an important role in the introduction of green innovations. In the case of Italy, Antonioli, Borghesi and Mazzanti [62] find that being based in a certain municipality with a higher share of green innovations increases the likelihood that a firm will introduce green innovations, as firms learn about the benefits of green innovations. Horbach and Rammer [40] show that both the orientation of a region towards green issues (measured by the share of green voters within a region) and the physical proximity to sources of renewable energy are positively linked to the introduction of green innovations. Quatraro and Scandura [73] find that local spillovers from non-green technological areas and academic investors involved in patenting have direct positive effects on the generation of green technologies.

On the basis of this evidence, we propose to test the following hypothesis:

Hypothesis H5. *Spillovers from other green innovators enhance firms' propensity to introduce green innovations.*

2.6. Public Funding

Cainelli and Mazzanti [74] find that public funding played an important role for the introduction of innovations with environmental benefits in the areas of carbon abatement and energy efficiency in the Italian service industries. However, Borghesi, Cainelli, and Mazzanti [36] find no effect of public funding on the innovation performance of firms in the sectors under the European Union's Emissions Trading System (EU ETS) regulations. In a study on South Korea, Castellacci and Lie [46] find that public funding is an important determinant of innovations with environmental benefits in the area of waste and carbon dioxide reducing sectors.

Peñasco, del Río, and Romero-Jordán [37] show that in Spain, international public subsidies do not increase the likelihood of introducing green innovations, whereas national public funding does. In contrast to these results, Rogge and Schleich [75] find that public funding to German firms matters for the introduction of green innovations conditional on firms' accessibility to both domestic and EU funding. Using data from 16 EU countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom), Jaumotte and Pain [54] find that green innovations in small firms are dependent on the availability of finance and co-operation to a larger extent than in larger firms. Bai et al. 2019 [13] provide evidence from China showing that government R&D subsidies fostered green innovations of energy-intensive firms. Further, they find that the effects were larger in state-owned and small- and medium-sized enterprises.

Taken together, the evidence discussed above suggests the following testable hypothesis:

Hypothesis H6. *Public funding fosters the introduction of green innovations*.

In summary, international evidence uncovers a range of factors which influence the decisions of firms to introduce green innovations, including environmental regulations; innovation inputs such as investment in R&D and access to external knowledge; firm-specific factors, such as energy intensity, human capital, and absorptive capacity; international and domestic competition; spillovers from other green innovators; and public funding.

Taking this international evidence as the point of departure, we design and use a unified econometric framework to examine and empirically test the importance of these factors for the propensity of firms to introduce green innovations. In addition to average effects across all firms, we allow and account for a heterogenous innovation behaviour across groups of firms.

3. Data and Methods

3.1. Data and Descriptive Analysis

The main data source for this research is the Community Innovation Survey (CIS) 2014 for Ireland undertaken by the Central Statistics Office (CSO). The data set contains information on innovation activities of 3036 firms over the period 2012–2014.

The Community Innovation Survey distinguishes two categories of green innovations according to the final beneficiary: innovations with environmental benefits obtained within the enterprise and innovations with environmental benefits for the end user. Innovations with environmental benefits obtained within the enterprise are defined as product, process, organisational, or marketing innovations with any of the following benefits obtained within the enterprise: reduced material or water use per unit of output; reduced energy use or CO_2 "footprint"; reduced air, water, noise or soil pollution; replaced a share of materials with less polluting or hazardous substitutes; replaced a share of fossil energy with renewable energy sources; and recycled waste, water, or materials for own use or sale. Innovations with environmental benefits for the end user are product, process, organisational, or marketing innovations with any of the following benefits obtained during the consumption or the use of a good or service by the end user: reduced energy use or CO_2 "footprint"; reduced air, water, noise or soil pollution; facilitated recycling of product after use; and extended product life through longer-lasting, more durable products.

Table 1 shows the proportion of firms reporting innovations with environmental benefits by firm size. The CIS considers three firm size categories: small (with 10–49 employees), medium-sized (with 50–249 employees), and large firms (with 250 and more employees). As shown in Table 1, an average of 40.1% of firms introduced innovations with environmental benefits over the survey period. The likelihood of introducing green innovations increases with firm size. While only 34.6% of small firms introduced green innovations between 2012 and 2014, 67.1% of large firms did so.

Table 1. The rate of green innovations by firm size group %.

	All Green Innovations	Green Innovations with within Firm Benefits	Green Innovations with Benefits for the Final User
All firms	40.1	34.0	28.0
Small firms	34.6	27.9	25.0
Medium-sized firms	46.1	41.0	30.5
Large firms	67.1	30.5	45.7

Source: Authors' calculations based on data from the Community Innovation Survey 2014, CSO.

Table 1 also shows summary statistics for green innovations with benefits within the enterprise by firm size. Overall, 34% of firms reported the introduction of this type of green innovation between 2012 and 2014. The innovation rate increases with firm size. Large and medium-sized firms have rates above the average innovation rate across all firms: 63.7%

and 41.0%, respectively. Further, Table 1 shows the distribution of innovations with environmental benefits for the end user across firm sizes. This type of green innovation tends to be less frequent than green innovations with benefits obtained within the enterprise. Only 28% of responding firms report having undertaken any green innovations for the benefit of end users. Once again, we find that the likelihood of introducing green innovations with benefits for the end user increases with firm size.

Table 2 reports the innovation rates across sectors defined according to the NACE Rev.2 classification (NACE Rev. 2, is the current classification of economic activities in the European Union used by the European Statistics Office (Eurostat). An overview of the NACE Rev. 2 classification is available from the Eurostat at the following web link: https://ec.europa.eu/eurostat/web/nace-rev2, accessed on 8 July 2022). Sector-specific rates for green innovations vary as shown below. Utility industries such as electricity, gas, water, and sewerage have the highest green innovation rate (over 65%), followed by manufacturing (55%), mining and quarrying (41%), and services. Across the services sector, the highest green innovation rate is in transport and storage and the lowest in information and communication.

Table 2. The rate of green innovations by sector %.

	All Green Innovations	Green Innovations with within Firm Benefits	Green Innovations with Benefits for the Final User
All firms	40.1	34.0	28.0
Mining and quarrying	40.7	40.7	37.0
Manufacturing	54.7	49.3	38.0
Electricity, gas, steam and air conditioning	66.7	66.7	50.0
Water supply, waste management	65.5	54.5	54.5
Wholesale and retail trade	36.6	29.5	26.5
Transportation and storage	39.4	35.0	25.2
Information and communication	23.6	18.0	16.6
Financial and insurance activities	26.3	21.2	15.0
Professional, scientific, technical activities	37.2	26.8	29.5

Source: Authors' calculations based on data from the Community Innovation Survey 2014, CSO.

Table 2 also shows summary statistics of green innovations with benefits within the enterprise across sectors. The results are qualitatively similar to those for all green innovations. A difference worth noting is that the innovation rate for transportation and storage is higher than the average rate.

Further, Table 2 shows summary statistics of green innovations with benefits for the end user across sectors. While the sectoral patterns are broadly similar to those for all green innovations, a number of differences stand out. Firms in professional, scientific, and technical activities report a larger rate of this type of green innovation than the average across all firms. Further, firms in transportation and storage with a higher than average rate of green innovations with benefits for the enterprise have an innovation rate below the average for green innovations with benefits for the end user.

Taken together, the descriptive analysis discussed above indicates that the propensity of firms to introduce green innovations varies across groups of firms and industries. In addition, the likelihood of introducing green innovations is different depending on whether the environmental benefits are obtained within the firm or during the consumption or use of goods or services by the end user. This evidence informs the empirical approach and the design of a multivariate econometric model empirical that we discuss next.

3.2. Empirical Approach and Model Specification

The baseline econometric model to identify the main factors that influence firms' decisions to introduce innovations with environmental benefits we estimate is specified as follows:

$$Prob\ (Y_i = 1 \mid \boldsymbol{X}_i) = F\ (\boldsymbol{X}_i, \beta) \quad (1)$$

The dependent variable Y_i is a binary variable that takes the value 1 if firm i implemented any innovation with environmental benefits during the analysed period. The vector $\boldsymbol{X}_i$ includes the following explanatory variables: an indicator variable for environmental regulations (a set of two dummies, which take the value 1 if the firm implemented procedures to regularly identify and reduce environmental impacts before and after the analysed period, respectively); innovation inputs (in-house R&D, external R&D, acquisition of capital assets, acquisition of external knowledge, and other innovation inputs); firm-specific factors including their productivity (at the beginning of the analysed period), size (employment quartiles), export performance (whether they exported to Europe or other markets), and ownership (indigenous or foreign-owned); a measure of spillovers from other green innovators (the NACE 2 industry-level share of firms that implemented an environmental innovation, other than a given firm i (model specifications include measures of spillovers accounting for innovations with environmental benefits within the enterprise and for the end user, separately)).

Further co-variates control for the role of public funding in introducing green innovations (three binary variables taking the value 1 if the firm obtained public financial support to implement green innovations from local/regional authorities, the central government or the European Union) and co-operation for innovation (eight categorical variables accounting for co-operations for green innovations with: enterprises within the same enterprise group; suppliers; private and public clients; competitors; consultants; universities and the government). Finally, we control for unobserved sector characteristics that could influence the propensity of firms to introduce green innovations.

We first estimate this model for all firms. Subsequently, we replicate the analysis for four groups of firms: manufacturing, services, indigenous, and foreign-owned firms. Further, we disaggregate the dependent variable to account for two types of environmental innovation according to the innovation beneficiary, namely, the enterprise itself or the end user.

Detailed definitions of variables used in the empirical analysis and their data sources are given in Table A1 in the Appendix A.

4. Results and Discussion

4.1. Baseline Results

Table 3 shows the estimates of the baseline model on factors influencing the propensity of firms to introduce green innovations across all firms as well as groups of firms in manufacturing, services, indigenous, and foreign-owned firms. The results for all firms shown in column 1 indicate that, on average, the propensity to introduce green innovations is higher for firms that have in place procedures to regularly identify and reduce the firm's environmental impacts. Having in place such procedures in the period before 2012 increases the probability of introducing green innovations by 9 percentage points. The effect is higher for environmental regulations implemented during the analysed period 2012–2014, at 25.6 percentage points. These results are consistent with theoretical predictions [22,23] and previous empirical evidence from Ireland [43] and other small economies [44,45], as well as from large countries [20,32–34,36,37] and cross-country analyses [26–31].

Table 3. Estimates on factors enabling green innovations.

Dependent Variable: Innovation with Environmental Benefits 2012–2014	All Firms	Manufacturing	Services	Indigenous	Foreign-Owned
Environmental regulations					
Before 2012	0.092 ***	0.012	0.138 ***	0.089 ***	0.111 ***
	(0.020)	(0.033)	(0.025)	(0.023)	(0.035)
Between 2012 and 2014	0.256 ***	0.291 ***	0.242 ***	0.263 ***	0.236 ***
	(0.018)	(0.028)	(0.025)	(0.022)	(0.034)
Innovation inputs					
In-house R&D	0.063 ***	0.019	0.069 **	0.074 ***	0.003
	(0.024)	(0.037)	(0.031)	(0.028)	(0.048)
External R&D	0.000	0.044	-0.030	0.008	−0.014
	(0.028)	(0.047)	(0.036)	(0.034)	(0.050)
Machinery, equipment, software & buildings	0.106 ***	0.134 ***	0.096 ***	0.108 ***	0.090 **
	(0.020)	(0.034)	(0.026)	(0.023)	(0.043)
Other external knowledge	0.063 **	0.007	0.095 ***	0.082 ***	−0.0123
	(0.026)	(0.045)	(0.033)	(0.030)	(0.056)
Other innovation activities	0.060 **	0.086 *	0.040	0.075 **	0.040
	(0.029)	(0.047)	(0.038)	(0.034)	(0.055)
Firm-specific factors					
Productivity 2012	−0.002	−0.004	0.000	−0.002	0.001
	(0.003)	(0.006)	(0.003)	(0.003)	(0.006)
Size (employment quartile)	0.026 ***	0.048 ***	0.011	0.031 ***	0.019
	(0.008)	(0.015)	(0.010)	(0.009)	(0.018)
Exported to Europe	−0.015	−0.023	−0.010	−0.029	0.036
	(0.019)	(0.037)	(0.023)	(0.022)	(0.047)
Exported to other destinations	−0.021	−0.045	−0.020	−0.022	−0.012
	(0.021)	(0.034)	(0.026)	(0.025)	(0.041)
Ownership					
Indigenous firm	0.007	0.026	0.011		
	(0.022)	(0.040)	(0.026)		
USA ownership					−0.067 *
					(0.039)
EU ownership					0.010
					(0.044)
Spillovers (industry level)	−0.123	−0.032	0.610 ***	−0.151	0.046
	(0.110)	(0.123)	(0.145)	(0.125)	(0.216)
Public funding					
Local/Regional authorities	0.084 *	0.035	0.145 **	0.072	0.172
	(0.046)	(0.067)	(0.062)	(0.052)	(0.108)
Central government	0.012	0.053	−0.076 *	−0.003	0.084
	(0.030)	(0.042)	(0.043)	(0.034)	(0.062)
European Union	0.011	0.074	-0.066	0.036	−0.121
	(0.059)	(0.080)	(0.098)	(0.062)	(0.149)
Co-operation for innovation					
Within enterprise group	0.075 *	0.079	0.071	0.020	0.112 *
	(0.039)	(0.075)	(0.047)	(0.052)	(0.061)
With suppliers	0.020	0.096	0.027	0.008	0.039
	(0.041)	(0.078)	(0.049)	(0.048)	(0.079)
With private clients	0.071	0.155 *	−0.012	0.090	0.057
	(0.045)	(0.082)	(0.058)	(0.055)	(0.076)
With public clients	−0.017	−0.040	0.024	0.009	−0.041
	(0.060)	(0.095)	(0.077)	(0.072)	(0.117)
With competitors	0.121 **	0.021	0.167 **	0.134 **	0.123
	(0.059)	(0.086)	(0.076)	(0.066)	(0.144)
With consultants, private R&D	−0.010	−0.114	0.032	−0.041	0.0617
	(0.050)	(0.091)	(0.061)	(0.059)	(0.083)

Table 3. *Cont.*

Dependent Variable: Innovation with Environmental Benefits 2012–2014	All Firms	Manufacturing	Services	Indigenous	Foreign-Owned
With universities, higher education institutes	−0.024	0.066	−0.101	−0.054	0.027
	(0.046)	(0.079)	(0.066)	(0.053)	(0.087)
With government	−0.045	−0.048	−0.019	−0.049	0.057
	(0.059)	(0.097)	(0.085)	(0.069)	(0.151)
Sector fixed effects	Yes	No	No	Yes	Yes
N	2763	854	1827	2137	624
Pseudo R^2	0.220	0.267	0.167	0.212	0.274
Chi2	686.8	278.0	353.9	504.9	200.5

Source: Authors' estimates obtained from a probit regression model using data from the Community Innovation Survey 2014, CSO. Notes: The figures reported in the table are marginal effects. Robust standard errors are reported in parentheses. *, **, *** denote significance at 10%, 5%, and 1%, respectively.

Looking at different groups of firms, environmental regulations implemented before 2012 had the strongest effect on the propensity of service firms to introduce green innovations (13.8 percentage points) while they did not matter significantly for the introduction of green innovations by manufacturing firms. Previous environmental regulations had a stronger effect for foreign-owned firms (11.1 percentage points) relative to indigenous firms (8.9 percentage points). Environmental regulations implemented or changed significantly during the 2012–2014 period had positive and significant effects on the introduction of green innovations in all groups of firms with the strongest effect for manufacturing firms (29.1 percentage points).

Taken together, these estimates suggest the growing importance over time of policy-induced green innovations across enterprises via environmental regulations.

In terms of innovation inputs, the propensity of firms to introduce green innovations is higher for firms with in-house R&D; acquisition of machinery, equipment, software, and buildings; acquisition of other external knowledge from other enterprises or institutions; and innovation activities other than product and process innovation (non-technological innovations). These results are similar to findings from previous studies [14,32,36,46,49–51,54]. This pattern is similar for indigenous firms, while in the case of foreign-owned firms, only the acquisition of machinery, equipment, software, and buildings is positively and significantly associated with the introduction of green innovations. In comparison with the average effects across all firms, for manufacturing firms, in-house R&D and the acquisition of other external knowledge do not significantly affect the propensity to introduce green innovations. Firms in services have a similar behaviour as the average firm with the exception of other non-technological innovations which do not have a significant effect on the introduction of green innovations.

Our results indicate that firms engaged in co-operation for innovation with firms in the same enterprise group, and with competitors are more likely to introduce green innovations. These results are consistent with findings of previous studies [37,43,46,49,54]. The effect of co-operations with firms in the same enterprise group is present for foreign-owned firms, while the positive effect of co-operation with competitors is identified for firms in services and for indigenous firms. For manufacturing firms, co-operation with private clients increase their propensity to introduce green innovations.

Larger firms are more likely to introduce green innovations. This result holds for all firms as well as all groups of firms, with the exception of firms in services. In contrast to evidence from other countries [32,34,47], we find that export participation does not appear to be associated with the propensity of firms to introduce green innovations. This result is similar to findings from Spain [37,71].

The propensity of service firms to introduce green innovations is higher for firms in the same industry with green innovators. This spillover effect is not identified in the case of the other groups of firms. While evidence on spillovers from other green innovators in the same region has been previously provided [40,62], to the best of our knowledge, spillovers from green innovators in the same industry have not been investigated so far.

Finally, in contrast with previous evidence [13,46,74], we find only limited evidence that public funding influences the introduction of green innovations. More specifically, our results indicate a positive albeit marginally significant effect in the case of funding from local authorities. This result is consistent with evidence from Spain [37]. This effect appears to be driven by firms in services while it does not appear in the case of the other groups of firms.

Table 4 summarises the empirical evidence corresponding to the six research hypotheses discussed in Section 2.

Table 4. Factors enhancing the propensity of firms to introduce green innovations: Summary of research hypotheses and empirical evidence.

Research Hypotheses	Empirical Evidence
H1: Environmental regulations	All firms and groups of firms
H2: Innovation inputs such as internal R&D, technological capabilities, and access to external technological knowledge	All firms, firms in manufacturing, and indigenous firms
H3: Firm-specific factors such as size, ownership, entrepreneurship, and absorptive capacity	All firms, firms in manufacturing, and indigenous firms
H4: Exposure to competition from international markets	Factor is not significant
H5: Spillovers from other green innovators	Firms in services
H6: Public funding fosters the introduction of green innovations	Local funding for firms in services

Source: Authors' elaboration.

The strongest empirical support is found for the impact of environmental regulations on fostering green innovations (H1). This evidence is found for all firms and all groups of firms. The evidence also supports the role played by innovation inputs (H2) and firm-specific factors (H3) on the propensity of all firms, firms in manufacturing, and indigenous firms to introduce green innovations. Exposure to competition in international markets does not appear to have a significant impact on the propensity of firms to introduce green innovations (H4). The evidence on spillovers from other green innovators on the propensity of firms to introduce green innovations (H5) is limited to firms in services. Finally, we find limited evidence on the role of public funding on fostering the adoption of green innovations; this is the case of local funding for firms in services (H6).

4.2. Green Innovations with Benefits for the Enterprise and for the End User

Tables 5 and 6 show the results of determinants of green innovations with enterprise benefits and for the end user, respectively. Table 7 summarises the empirical evidence corresponding to the six testable hypotheses. A number of similarities and differences emerge. On the similarities side, environmental regulations play an important role in enabling both types of green innovations with a similar pattern (no significant effect of previous regulations in the case of manufacturing firms). In terms of innovation inputs, in-house R&D activity is associated with both types of green innovations across all firms and for indigenous firms, and no significant effect in the case of foreign-owned firms. While in-house R&D increases the likelihood of green innovations with benefits for service firms, it does not have a significant effect in the case of green innovations with benefits for the end user in services. In the case of manufacturing firms, in-house R&D is positively associated with the introduction of green innovations with benefits for the end user, but not in the case of green innovations with enterprise benefits.

Table 5. Determinants of green innovations—green innovations with within firm benefits.

Dependent Variable: Innovation with Environmental Benefits within the Enterprise 2012–2014	All Firms	Manufacturing	Services	Indigenous	Foreign-Owned
Environmental regulations					
Before 2012	0.071 ***	0.011	0.101 ***	0.068 ***	0.086 **
	(0.019)	(0.033)	(0.023)	(0.022)	(0.035)
Between 2012 and 2014	0.247 ***	0.270 ***	0.237 ***	0.249 ***	0.247 ***
	(0.017)	(0.028)	(0.022)	(0.020)	(0.032)
Innovation inputs					
In-house R&D	0.061 ***	0.004	0.082 ***	0.065 **	0.024
	(0.023)	(0.037)	(0.029)	(0.027)	(0.046)
External R&D	−0.020	0.010	−0.043	−0.016	−0.021
	(0.026)	(0.045)	(0.033)	(0.031)	(0.047)
Machinery, equipment, software & buildings	0.101 ***	0.127 ***	0.091 ***	0.108 ***	0.072 *
	(0.020)	(0.034)	(0.024)	(0.022)	(0.041)
Other external knowledge	0.038	0.036	0.051	0.054 *	−0.024
	(0.025)	(0.044)	(0.031)	(0.029)	(0.053)
Other innovation activities	0.053 *	0.082 *	0.035	0.063 **	0.045
	(0.027)	(0.046)	(0.034)	(0.031)	(0.052)
Firm-specific factors					
Productivity 2012	−0.002	−0.001	−0.001	−0.003	0.002
	(0.002)	(0.006)	(0.003)	(0.003)	(0.005)
Size (employment quartile)	0.027 ***	0.058 ***	0.012	0.030 ***	0.031 *
	(0.008)	(0.015)	(0.009)	(0.008)	(0.018)
Exported to Europe	−0.010	0.016	−0.017	−0.023	0.044
	(0.019)	(0.039)	(0.021)	(0.021)	(0.046)
Exported to other destinations	−0.025	−0.030	−0.032	−0.022	−0.033
	(0.020)	(0.034)	(0.025)	(0.024)	(0.040)
Ownership					
Indigenous firm	−0.003	0.023	−0.005		
	(0.021)	(0.040)	(0.024)		
USA ownership					−0.053
					(0.039)
EU ownership					0.038
					(0.042)
Spillovers (innovations with benefits within the enterprise, industry level)	−0.043	−0.052	0.685 ***	−0.093	0.150
	(0.104)	(0.128)	(0.139)	(0.122)	(0.196)
Public funding					
Local/Regional authorities	0.048	−0.006	0.105 *	0.041	0.106
	(0.043)	(0.066)	(0.058)	(0.048)	(0.105)
Central government	0.009	0.038	−0.064	-0.015	0.100 *
	(0.028)	(0.042)	(0.040)	(0.032)	(0.059)
European Union	−0.008	0.095	−0.132	0.007	−0.038
	(0.055)	(0.079)	(0.090)	(0.059)	(0.125)
Co-operation for innovation					
Within enterprise group	0.060 *	0.049	0.060	−0.021	0.121 **
	(0.036)	(0.070)	(0.043)	(0.047)	(0.061)
With suppliers	−0.005	0.084	−0.017	−0.026	0.018
	(0.038)	(0.073)	(0.046)	(0.045)	(0.073)
With private clients	0.078 *	0.098	0.031	0.111 **	0.043
	(0.042)	(0.074)	(0.053)	(0.051)	(0.069)
With public clients	−0.039	0.037	−0.028	−0.042	0.023
	(0.054)	(0.097)	(0.067)	(0.065)	(0.111)
With competitors	0.096 *	0.009	0.137 **	0.096	0.159
	(0.053)	(0.099)	(0.063)	(0.060)	(0.129)

Table 5. *Cont.*

Dependent Variable: Innovation with Environmental Benefits within the Enterprise 2012–2014	All Firms	Manufacturing	Services	Indigenous	Foreign-Owned
With consultants, private R&D	0.010	−0.041	0.005	0.003	0.035
	(0.045)	(0.082)	(0.056)	(0.054)	(0.078)
With universities, higher education institutes	0.016	0.057	−0.017	0.004	0.029
	(0.042)	(0.072)	(0.060)	(0.050)	(0.085)
With government	−0.007	0.016	−0.009	0.013	−0.033
	(0.055)	(0.092)	(0.079)	(0.063)	(0.120)
Sector fixed effects	Yes	No	No	Yes	Yes
N	2763	854	1827	2137	626
Pseudo R^2	0.230	0.256	0.176	0.218	0.298
Chi2	697.3	265.6	345.3	495.8	212.8

Source: Authors' estimates based on data from the Community Innovation Survey 2014, CSO. Notes: The figures reported in the table are marginal effects. Robust standard errors are reported in parentheses. *, **, *** denote significance at 10%, 5%, and 1%, respectively.

Table 6. Determinants of green innovations—green innovations with benefits for the end user.

Dependent Variable: Innovation with Environmental Benefits for the End User 2012–2014	All Firms	Manufacturing	Services	Indigenous	Foreign-Owned
Environmental regulations					
Before 2012	0.082 ***	0.011	0.121 ***	0.080 ***	0.098 ***
	(0.019)	(0.035)	(0.023)	(0.022)	(0.036)
Between 2012 and 2014	0.177 ***	0.222 ***	0.163 ***	0.190 ***	0.146 ***
	(0.018)	(0.032)	(0.023)	(0.021)	(0.037)
Innovation inputs					
Inhouse R&D	0.058 **	0.072 *	0.040	0.054 **	0.065
	(0.023)	(0.040)	(0.028)	(0.026)	(0.045)
External R&D	0.016	0.062	−0.012	0.009	0.032
	(0.025)	(0.045)	(0.032)	(0.031)	(0.046)
Machinery, equipment, software & buildings	0.073 ***	0.058	0.086***	0.092 ***	0.013
	(0.020)	(0.038)	(0.024)	(0.022)	(0.044)
Other external knowledge	0.063 ***	0.059	0.049	0.071 **	0.024
	(0.024)	(0.043)	(0.030)	(0.028)	(0.051)
Other innovation activities	0.011	0.034	−0.002	0.008	0.029
	(0.026)	(0.045)	(0.034)	(0.031)	(0.049)
Firm-specific factors					
Productivity 2012	−0.001	−0.003	0.001	−0.000	−0.004
	(0.002)	(0.006)	(0.003)	(0.003)	(0.005)
Size (employment quartile)	0.014 *	0.024	0.008	0.022 ***	−0.019
	(0.008)	(0.016)	(0.009)	(0.009)	(0.019)
Exported to Europe	−0.024	−0.098 **	−0.001	−0.042 **	0.036
	(0.019)	(0.041)	(0.021)	(0.021)	(0.047)
Exported to other destinations	−0.014	−0.029	−0.007	−0.009	0.007
	(0.020)	(0.036)	(0.024)	(0.023)	(0.040)
Ownership					
Indigenous firm	0.062 ***	0.117 ***	0.046 *		
	(0.022)	(0.043)	(0.025)		
USA ownership					−0.032
					(0.040)
EU ownership					0.016
					(0.041)

Table 6. *Cont.*

Dependent Variable: Innovation with Environmental Benefits for the End User 2012–2014	All Firms	Manufacturing	Services	Indigenous	Foreign-Owned
Spillovers (innovations with benefits for the end user, industry level)	−0.168	−0.034	0.467 ***	−0.153	−0.169
	(0.125)	(0.165)	(0.161)	(0.143)	(0.269)
Public funding					
Local/Regional authorities	0.017	−0.017	0.069	0.007	0.053
	(0.040)	(0.063)	(0.054)	(0.045)	(0.103)
Central government	0.015	0.056	−0.041	0.021	0.003
	(0.027)	(0.042)	(0.038)	(0.031)	(0.053)
European Union	0.068	0.153 *	−0.033	0.073	0.060
	(0.052)	(0.078)	(0.084)	(0.056)	(0.120)
Co-operation for innovation					
Within enterprise group	0.090 ***	0.123 *	0.084 **	0.100 **	0.053
	(0.035)	(0.067)	(0.041)	(0.047)	(0.054)
With suppliers	−0.036	−0.027	−0.011	−0.089 *	0.082
	(0.037)	(0.066)	(0.044)	(0.046)	(0.065)
With private clients	0.058	0.138 *	−0.047	0.090 *	0.014
	(0.041)	(0.072)	(0.053)	(0.051)	(0.066)
With public clients	0.020	-0.057	0.088	0.041	−0.039
	(0.053)	(0.093)	(0.067)	(0.065)	(0.095)
With competitors	0.166 ***	0.193 **	0.150 **	0.165 ***	0.197 *
	(0.050)	(0.091)	(0.063)	(0.059)	(0.104)
With consultants, private R&D	−0.018	−0.102	0.033	−0.028	0.012
	(0.043)	(0.076)	(0.054)	(0.053)	(0.071)
With universities, higher education institutes	−0.032	−0.008	−0.060	−0.030	−0.018
	(0.040)	(0.069)	(0.056)	(0.048)	(0.071)
With government	−0.042	−0.028	−0.028	−0.082	0.045
	(0.050)	(0.079)	(0.073)	(0.060)	(0.096)
Sector fixed effects	Yes	No	No	Yes	Yes
N	2763	854	1827	2137	624
Pseudo R^2	0.162	0.166	0.134	0.167	0.180
Chi2	487.5	168.7	252.5	384.5	127.8

Source: Authors' estimates based on data from the Community Innovation Survey 2014, CSO. Notes: The figures reported in the table are marginal effects. Robust standard errors are reported in parentheses. *, **, *** denote significance at 10%, 5%, and 1%, respectively.

Acquisitions of capital assets is an important driver of green innovations with enterprise benefits as well as of green innovations with benefits for the end user for all firms, and for all groups of firms with the exception of green innovations with benefits for the end user in manufacturing. Acquisition of other external knowledge increases the propensity of indigenous firms to introduce both types of green innovations while it does not appear to matter in the case of the other groups of firms. Other non-technological innovation activities have a significant effect on the propensity of all firms to introduce green innovations with enterprise benefits, as well as in the case of manufacturing and indigenous firms. In contrast, other non-technological innovation activities do not matter for the introduction of green innovations with benefits for the end user.

Larger firms are more likely to introduce both types of green innovations, with a stronger effect in the case of green innovations with enterprise benefits introduced by manufacturing firms and by indigenous firms. Firm size also has a strong effect on the propensity of indigenous firms to introduce green innovations with benefits for the end user. While export participation does not affect the propensity of firms to introduce green innovations with enterprise benefits, indigenous and manufacturing exporters to European countries are less likely to introduce green innovations with benefits for the end user.

Table 7. Factors enhancing the propensity of firms to introduce green innovations with benefits within firm: summary of testable research hypotheses and empirical evidence.

Research Hypotheses	Empirical Evidence: Green Innovations with Benefits within the Firm	Empirical Evidence: Green Innovations with Benefits for the Final User
H1: Environmental regulations	All firms and all groups of firms	All firms and all groups of firms
H2: Innovation inputs such as internal R&D, technological capabilities and access to external technological knowledge	All firms, firms in manufacturing and indigenous firms	All firms, firms in manufacturing and indigenous firms
H3: Firm specific factors such as size, ownership, entrepreneurship and absorptive capacity	All firms, indigenous firms	All firms, firms in manufacturing, indigenous and foreign-owned firms
H4: Exposure to competition from international markets	Negative effect for manufacturing and indigenous firms exporting to Europe; not significant effect in the other cases	Not significant factor
H5: Spillovers from other green innovators	Firms in services	Firms in services
H6: Public funding fosters the introduction of green innovations	Funding from local authorities for firms in services	Funding from the European Union for firms in manufacturing

Source: Authors' elaboration.

Spillovers from green innovators in the same industry play an important role for the introduction of both types of green innovations in services. Public funding from local authorities appears to incentivise firms in services to introduce green innovations with enterprise innovations. There is no evidence of similar effects in the case of government and EU funding. Relative to other firms, indigenous firms are more likely to introduce green innovations with benefits for the end user. The result is stronger in the case of manufacturing firms in comparison to services firms.

In terms of co-operation for innovation activities, co-operation with firms from the same enterprise group and with competitors are important drivers of both types of green innovations with stronger effects in the case of innovations with environmental benefits for the end user. In this latter case, co-operation with competitors increases the likelihood of the introduction of green innovations for all groups of firms, with the largest effects found for manufacturing firms and for foreign-owned firms.

Table 7 compares the evidence found for the six testable hypotheses for the two types of innovations with environmental benefits within the firm and for the final user, respectively. The evidence is similar for three hypotheses (H1, H2, and H5) and it differs in the case of the other three hypotheses (H3, H4, and H6).

4.3. Scientific Value Added, Limitations, Policy Implications and Future Directions for Research

Our research results contribute to a better understanding of a broad range of factors that influence the propensity of firms to introduce green innovations and enhance the transition to a circular economy. To the best of our knowledge, we contribute to the academic literature in three ways. First, we bring together several literature strands and design a unified econometric framework to analyse a comprehensive set of factors that influence the introduction of green innovations across firms. Second, we allow for and uncover a heterogeneous innovation behaviour across different groups of firms and sectors as well as two types of environmental benefits of innovations. Third, we provide new evidence on spillovers from other green innovators in the same industry on the propensity of firms to introduce green innovations.

These results also have implications for policies aiming at enabling more enterprises to introduce green innovations and thus accelerate the transition to a circular economy and a more sustainable long-term growth. More specifically, our findings suggest that targeted policy measures aiming at incentivising small- and medium-sized enterprises and enterprises in the services sector introduce innovations with environmental benefits, which could be beneficial to achieving that goal. Demand-side policies, such as public procurement of green products, could incentivise enterprises to introduce innovations with environmental benefits for the end user, which have been introduced at a lower rate relative to green innovations with benefits within enterprises. Furthermore, fostering linkages between enterprises and co-operation for innovation activities could enhance spillovers from green innovators and increase the propensity of enterprises to introduce innovations with environmental benefits.

Our analysis is subject to a number of data limitations. First, while we use the most recent available data on green innovations, these data have been collected with the 2014 wave of the Community Innovation Survey. It would be desirable and useful to analyse more recent data when they become available. Second, our results are obtained with a cross-section data, and they reflect structural relationships rather than causality. Third, our data does not distinguish start-ups from incumbent firms; we cannot therefore identify any differences in the innovation behaviour of start-ups and incumbent firms.

Given the importance of green innovations for fostering a sustainable circular economy, we suggest that our research can be extended in a number of directions: collecting and analysing primary data on the implementation of green innovations for the circular economy; analysing the propensity of start-ups to introduce green innovations and comparing it with the propensity of incumbents; examining the role of digital technologies and other disruptive technologies in fostering the introduction of green innovations; and identifying barriers faced by enterprises to introducing green innovations.

5. Conclusions

This paper put forward and tested six research hypotheses relating to a broad range of factors that influence the propensity of firms to introduce innovations with environmental benefits. Using micro data from Ireland, we analysed a comprehensive set of such factors, including environmental regulations, innovation inputs, firm-specific characteristics, spillovers from other firms with green innovations (in the same industry), co-operation for innovation activities, and public funding. We first analysed the propensity of firms to introduce any green innovations and second, we separately examined the propensity of firms to introduce innovations with environmental benefits obtained within the firm and innovations with benefits obtained during the consumption or use of goods and services by the end user. In addition to average effects across all firms, to account for potentially different innovation behaviours for different groups of firms, we separately analysed manufacturing and service firms and indigenous and foreign-owned firms.

Taken together, our key results can be summarised as follows:

- The propensity of firms to introduce green innovations varies across groups of firms and industries.
- The rate of green innovation is lower in small- and medium-sized firms than in large firms and in the services sector compared with the manufacturing and the utilities sectors.
- The green innovation rate is lower in the case of innovations with benefits for the end user than the case of innovations with benefits within the firm.
- Environmental regulations, in-house R&D, and acquisition of capital assets are major drivers of green innovations.
- Larger firms are more likely to introduce green innovations. This result holds for all firms as well as all groups of firms with the exception of firms in services.
- The propensity of service firms to introduce green innovations is higher for firms in the same industry with green innovators. Such a spillover effect is not identified in the case of the other groups of firms.
- Relative to foreign-owned firms, indigenous firms are more likely to introduce green innovations with benefits for the end user. This result holds across all firms as well as for manufacturing and service firms.

- Firms engaged in co-operation for innovation with other firms in the same enterprise group and with competitors are more likely to introduce green innovations. The effect of co-operations with firms in the same enterprise group is driven by foreign-owned firms while the positive effect of co-operations with competitors is driven by firms in services and indigenous firms. Co-operation with private clients increases the propensity of firms to introduce green innovations.
- Public funding appears to play a limited role in fostering the introduction of green innovations. Our results indicate a positive albeit only marginally significant effect in the case of funding from local authorities on the propensity of firms to introduce green innovations. This effect appears to be driven by firms in services while it does not appear to be statistically significant in the case of the other groups of firms. Public funding from the European Union is found to be positively and significantly associated with green innovations with benefits for the end user in the case of more durable products. This effect is identified for manufacturing firms and for indigenous firms. It is not statistically significant in the case of firms in services and foreign-owned firms.

Taken together, the research-based evidence provided by this article informs the design of policy instruments aiming to incentivise firms to introduce innovations with environmental benefits and thus enhance a sustainable circular economy.

Author Contributions: Conceptualization, I.S.; methodology, I.S. and M.T.K.; software, M.T.K.; validation, I.S.; formal analysis, I.S., S.M. and M.T.K.; investigation, I.S., S.M. and M.T.K.; resources, I.S.; data curation, S.M. and M.T.K.; writing—original draft preparation, I.S., S.M. and M.T.K.; writing—review and editing, I.S.; visualization, S.M. and M.T.K.; supervision, I.S.; project administration, I.S.; funding acquisition, I.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Economic and Social Research Institute's Environment Research Programme, which is funded by the Environmental Protection Agency (EPA), Ireland (Grant Number: 2019-HW-MS-15). The EPA Research Programme is a Government of Ireland initiative funded by the Department of the Environment, Climate and Communications.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Results are based on strictly controlled Research Microdata Files provided by the Central Statistics Office (CSO). The CSO does not take any responsibility for the views expressed or the outputs generated from this research.

Acknowledgments: This article is an improved version of our research paper entitled "Determinants of green innovations: Firm-level evidence", by Iulia Siedschlag, Stefano Meneto and Manuel Tong Koecklin, circulated as an ESRI Working Paper No. 643, November 2019. The ESRI Working Papers are un-refereed work- in-progress and are disseminated via the ESRI website to bring about discussion with experts in the field and provide researchers the opportunity to get feedback on their work. We thank for useful comments and discussions on previous versions of this article the Academic Editors, four anonymous reviewers, Jonathan Derham, Corrado Di Maria, John FitzGerald, participants at the research conference on "Environmental Policy, Competitiveness and Green Growth", and at the international Symposium on "Circular Economy and Sustainability".

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Appendix A

Table A1. Definitions of Variables and Data Sources.

Dependent Variables	**Definition**	**Data Sources**
Innovation with environmental benefits	1 if firm implemented any innovation with environmental benefits between 2012 and 2014, 0 otherwise	CIS * 2014
Innovation with environmental benefits within the enterprise	1 if firm implemented any innovation with environmental benefits within the enterprise between 2012 and 2014, 0 otherwise	CIS 2014
Innovation with environmental benefits for the end user	1 if firm implemented any innovation with environmental benefits for the end user between 2012 and 2014, 0 otherwise	CIS 2014
Explanatory Variables		
Environmental Regulations		
Before 2012	1 if firm implemented procedures to regularly identify and reduce environmental impacts before 2012, 0 otherwise	CIS 2014
Between 2012 and 2014	1 if firm implemented or significantly changed procedures to regularly identify and reduce environmental impacts between 2012 and 2014, 0 otherwise	CIS 2014
Innovation inputs		
In-house R&D	1 if firm had in-house R&D, 0 otherwise	CIS 2014
External R&D	1 if firm had external R&D, 0 otherwise	CIS 2014
Machinery, equipment, software & buildings	1 if firm acquired machinery, equipment, software or buildings, 0 otherwise	CIS 2014
Other external knowledge	1 if firm made use of other external knowledge from other enterprises or institutions, 0 otherwise	CIS 2014
Other innovation activities	1 if firm implemented any other innovation activity, 0 otherwise	CIS 2014
Firm-specific factors		
Productivity 2012	Log of turnover/employment in 2012	CIS 2014
Size (employment quartile)	Firm size by number of employees (employment quartile)	CIS 2014
Exported to Europe	1 if firm exported to Northern Ireland, other EU countries, EFTA or EU candidates, 0 otherwise	CIS 2014
Exported to other destinations	1 if firm exported to other countries, 0 otherwise	CIS 2014
Spillover from green innovators, all green innovators	The share of firms with green innovations in the same industry	CIS 2014
Spillover from green innovators, innovations with benefits obtained within the firm	The share of firms with innovations with environmental benefits obtained within the firm in the same industry	CIS 2014
Spillover from green innovators, innovations with benefits obtained by the end user	The share of firms with innovations with environmental benefits obtained by the end user in the same industry	CIS 2014
Public financial support		
Local/Regional authorities	1 if innovation funded by local or regional authorities, 0 otherwise	CIS 2014
Central government	1 if innovation funded by central government, 0 otherwise	CIS 2014
European Union	1 if innovation funded by the European Union, 0 otherwise	CIS 2014

Table A1. *Cont.*

Dependent Variables	Definition	Data Sources
Ownership		
Indigenous firm	1 if firm is domestic-owned, 0 otherwise	CIS 2014
USA ownership	1 if foreign-owned by US based multinational, 0 otherwise	CIS 2014
EU ownership	1 if foreign-owned by EU based multinational, 0 otherwise	CIS 2014
Co-operation for innovation		
With enterprise group	1 if co-operation with other enterprises in firms' enterprise group, 0 otherwise	CIS 2014
With suppliers	1 if co-operation with suppliers of equipment, materials, components or software, 0 otherwise	CIS 2014
With private clients	1 if co-operation with clients or costumers from the private sector, 0 otherwise	CIS 2014
With public clients	1 if co-operation with clients or custumers from the public sector, 0 otherwise	CIS 2014
With competitors	1 if co-operation with competitors or other enterprises in firm i's sector, 0 otherwise	CIS 2014
With consultants, private R&D	1 if co-operation with consultants, commercial labs or private R&D institutes, 0 otherwise	CIS 2014
With universities, higher education institutes	1 if co-operation with universities or other higher education institutions, 0 otherwise	CIS 2014
With government	1 if co-operation with government or public or private research institutions, 0 otherwise	CIS 2014

* Community Innovation Survey.

References

1. Suchek, N.; Fernandes, C.I.; Kraus, S.; Filser, M.; Sjögrén, H. Innovation and the Circular Economy: A Systematic Literature Review. *Bus. Strategy Environ.* **2021**, *30*, 3686–3702. [CrossRef]
2. Ghisellini, P.; Cialani, C.; Ulgiati, S. A Review on Circular Economy: The Expected Transition to a Balanced Interplay of Environmental and Economic Systems. *J. Clean. Prod.* **2016**, *114*, 11–32. [CrossRef]
3. Geissdoerfer, M.; Savaget, P.; Bocken, N.M.; Hultink, E.J. The circular economy—A new sustainability paradigm? *J. Clean. Prod.* **2017**, *143*, 757–768. [CrossRef]
4. Ana, D.J.; Mendonça, S. Lost in transition? Drivers and barriers in the eco-innovation road to the circular economy. *Ecol. Econ.* **2018**, *145*, 75–89.
5. Prieto-Sandoval, V.; Jaca, C.; Santos, J.; Baumgartner, R.J.; Ormazabal, M. Key strategies, resources, and capabilities for implementing circular economy in industrial small and medium enterprises. *Corp. Soc. Responsib. Environ. Manag.* **2019**, *26*, 1473–1484. [CrossRef]
6. Pieroni, M.P.P.; McAloone, T.C.; Pigosso, D.C.A. Business model innovation for circular economy and sustainability: A review of approaches. *J. Clean. Prod.* **2019**, *215*, 198–216. [CrossRef]
7. Sehnem, S.; de Queiroz, A.A.F.S.; Pereira, S.C.F.; dos Santos Correia, G.; Kuzma, E. Circular economy and innovation: A look from the perspective of organizational capabilities. *Bus. Strategy Environ.* **2022**, *31*, 236–250. [CrossRef]
8. Khanra, S.; Kaur, P.; Joseph, R.P.; Malik, A.; Dhir, A. A resource-based view of green innovation as a strategic firm resource: Present status and future directions. *Bus. Strategy Environ.* **2022**, *31*, 1395–1413. [CrossRef]
9. Lopez, F.J.D.; Bastein, Y.; Tukker, A. Business model innovation for resource-efficiency, circularity and cleaner production: What 143 cases tell us. *Ecol. Econ.* **2019**, *155*, 20–35. [CrossRef]
10. Linder, M.; Williander, M. Circular Business Model Innovation: Inherent Uncertainties. *Bus. Strategy Environ.* **2015**, *26*, 182–196. [CrossRef]
11. OECD. Towards Green Growth, Paris, Organization for Economic Cooperation and Development. 2011. Available online: http://www.oecd.org/dataoecd/37/34/48224539.pdf (accessed on 10 September 2019).
12. UNEP. Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication, United Nations Environment Programme. 2011. Available online: www.unep.org/greeneconomy (accessed on 10 September 2019).
13. Bai, Y.; Song, S.; Jiao, J.; Yang, R. The impacts of government R&D subsidies on green innovation: Evidence from Chinese energy-intensive firms. *J. Clean. Prod.* **2019**, *233*, 819–829. [CrossRef]
14. Duque-Grisales, E.; Aguilera-Caracuel, J.; Guerrero-Villegas, J.; García-Sánchez, E. Does green innovation affect the financial performance of Multilatinas? The moderating role of ISO 14001 and R&D investment. *Bus. Strategy Environ.* **2020**, *29*, 3286–3302. [CrossRef]
15. Timoshenkov, I.; Babenko, V.; Nashchekina, O.; Makovoz, O. Institutional Foundations of Ukraine's Transition to the Green Economy. *Res. World Econ.* **2020**, *11*, 16. [CrossRef]
16. Shao, S.; Hu, Z.; Cao, J.; Yang, L.; Guan, D. Environmental Regulation and Enterprise Innovation: A Review. *Bus. Strategy Environ.* **2020**, *29*, 1465–1478. [CrossRef]
17. Liao, Z.; Liu, Y. What drives environmental innovation? A meta-analysis. *Bus. Strategy Environ.* **2020**, *30*, 1852–1864. [CrossRef]
18. Awan, U.; Sroufe, R.; Shahbaz, M. Industry 4.0 and circular economy: A literature review and recommendations for future research. *Bus. Strategy Environ.* **2021**, *30*, 2038–2060. [CrossRef]
19. Li, X.; Huang, Y.; Li, J.; Liu, X.; He, J.; Dai, J. The Mechanism of Influencing Green Technology Innovation Behavior: Evidence from Chinese Construction Enterprises. *Buildings* **2022**, *12*, 237. [CrossRef]
20. Horbach, J.; Oltra, V.; Belin, J. Determinants and Specificities of Eco-Innovations Compared to Other Innovations—An Econometric Analysis for the French and German Industry Based on the Community Innovation Survey. *Ind. Innov.* **2013**, *20*, 523–543. [CrossRef]
21. Rennings, K. Redefining innovation—eco-innovation research and the contribution from ecological economics. *Ecol. Econ.* **2000**, *32*, 319–332. [CrossRef]
22. Porter, M.E. Essay: America's Green Strategy. *Sci. Am.* **1991**, *4*, 264.
23. Acemoglu, D.; Aghion, P.; Bursztyn, L.; Hemous, D. The Environment and Directed Technical Change. *Am. Econ. Rev.* **2012**, *102*, 131–166. [CrossRef] [PubMed]
24. Dechezleprêtre, A.; Sato, M. The Impacts of Environmental Regulations on Competitiveness. *Rev. Environ. Econ. Policy* **2017**, *11*, 183–206. [CrossRef]
25. Dechezleprêtre, A.; Koźluk, T.; Kruse, T.; Nachtigall, D.; De Serres, A. Do Environmental and Economic Performance Go Together? A Review of Micro-level Empirical Evidence from the Past Decade or So. *Int. Rev. Environ. Resour. Econ.* **2019**, *13*, 1–118. [CrossRef]
26. Andrea, F.; Giulio, G.; Valentina, M. Green Patents, Regulatory Policies and Research Networks Policies. *Res. Policy* **2018**, *47*, 1018–1031.
27. Crespi, F.; Ghisetti, C.; Quatraro, F. Environmental and innovation policies for the evolution of green technologies: A survey and a test. *Eurasian Bus. Rev.* **2015**, *5*, 343–370. [CrossRef]
28. Horbach, J. Empirical determinants of eco-innovation in European countries using the community innovation survey. *Environ. Innov. Soc. Transit.* **2016**, *19*, 1–14. [CrossRef]

29. Garrone, P.; Grilli, L.; Mrkajic, B. The role of institutional pressures in the introduction of energy-efficiency innovations. *Bus. Strategy Environ.* **2018**, *27*, 1245–1257. [CrossRef]
30. Stucki, T.; Woerter, M.; Arvanitis, S.; Peneder, M.; Rammer, C. How different policy instruments affect green product innovation: A differentiated perspective. *Energy Policy* **2018**, *114*, 245–261. [CrossRef]
31. Stojčić, N. Social and private outcomes of green innovation incentives in European advancing economies. *Technovation* **2021**, *104*, 102270. [CrossRef]
32. Horbach, J. Determinants of environmental innovation—New evidence from German panel data sources. *Res. Policy* **2008**, *37*, 163–173. [CrossRef]
33. Rennings, K.; Rammer, C. The Impact of Regulation-Driven Environmental Innovation on Innovation Success and Firm Performance. *Ind. Innov.* **2011**, *18*, 255–283. [CrossRef]
34. Jens, H.; Rammer, C.; Rennings, K. Determinants of Eco-Innovations by Type of Environmental Impact—The Role of Regulatory Push/Pull, Technology Push and Market Pull. *Ecol. Econ.* **2012**, *78*, 112–122.
35. Ketata, I.; Sofka, W.; Grimpe, C. The role of internal capabilities and firms' environment for sustainable innovation: Evidence for Germany. *R&D Manag.* **2015**, *45*, 60–75. [CrossRef]
36. Borghesi, S.; Cainelli, G.; Mazzanti, M. Linking emission trading to environmental innovation: Evidence from the Italian manufacturing industry. *Res. Policy* **2015**, *44*, 669–683. [CrossRef]
37. Peñasco, C.; del Río, P.; Romero-Jordán, D. Analysing the Role of International Drivers for Eco-innovators. *J. Int. Manag.* **2017**, *23*, 56–71. [CrossRef]
38. Leoncini, R.; Montresor, S.; Rentocchini, F. CO2-reducing innovations and outsourcing: Evidence from photovoltaics and green construction in North-East Italy. *Res. Policy* **2016**, *45*, 1649–1659. [CrossRef]
39. Ramanathan, R.; Black, A.; Nath, P.; Muyldermans, L. Impact of environmental regulations on innovation and performance in the UK industrial sector. *Manag. Decis.* **2013**, *48*, 1493–1513. [CrossRef]
40. Horbach, J.; Rammer, C. Energy transition in Germany and regional spill-overs: The diffusion of renewable energy in firms. *Energy Policy* **2018**, *121*, 404–414. [CrossRef]
41. Cui, J.; Dai, J.; Wang, Z.; Zhao, X. Does Environmental Regulation Induce Green Innovation? A Panel Study of Chinese Listed Firms. *Technol. Forecast. Soc. Chang.* **2022**, *176*, 121492. [CrossRef]
42. Hu, J.; Pan, X.; Huang, Q. Quantity or quality? The impacts of environmental regulation on firms' innovation–Quasi-natural experiment based on China's carbon emissions trading pilot. *Technol. Forecast. Soc. Change* **2020**, *158*, 120122. [CrossRef]
43. Justin, D.; Ryan, G. Regulation and Firm Perception, Eco-Innovation and Firm Performance. *Eur. J. Innov. Manag.* **2012**, *15*, 421–441.
44. Veugelers, R. Which Policy Instruments to Induce Clean Innovating? *Res. Policy* **2012**, *41*, 1770–1778. [CrossRef]
45. Van Leeuwen, G.; Mohnen, P. Revisiting the Porter hypothesis: An empirical analysis of Green innovation for the Netherlands. *Econ. Innov. New Technol.* **2017**, *26*, 63–77. [CrossRef]
46. Castellacci, F.; Lie, C.M. A taxonomy of green innovators: Empirical evidence from South Korea. *J. Clean. Prod.* **2017**, *143*, 1036–1047. [CrossRef]
47. Horbach, J. Do eco-innovations need specific regional characteristics? An econometric analysis for Germany. *Rev. Reg. Res.* **2014**, *34*, 23–38. [CrossRef]
48. Cainelli, G.; Mazzanti, M.; Montresor, S. Environmental Innovations, Local Networks and Internationalization. *Ind. Innov.* **2012**, *19*, 697–734. [CrossRef]
49. Cainelli, G.; De Marchi, V.; Grandinetti, R. Does the development of environmental innovation require different resources? Evidence from Spanish manufacturing firms. *J. Clean. Prod.* **2015**, *94*, 211–220. [CrossRef]
50. Awan, U.; Arnold, M.G.; Gölgeci, I. Enhancing green product and process innovation: Towards an integrative framework of knowledge acquisition and environmental investment. *Bus. Strategy Environ.* **2021**, *30*, 1283–1295. [CrossRef]
51. Awan, U.; Nauman, S.; Sroufe, R. Exploring the effect of buyer engagement on green product innovation: Empirical evidence from manufacturers. *Bus. Strategy Environ.* **2021**, *30*, 463–477. [CrossRef]
52. Badillo, E.R.; Moreno, R. Does absorptive capacity determine collaboration returns to innovation? A geographical dimension. *Ann. Reg. Sci.* **2018**, *60*, 473–499. [CrossRef]
53. Rasi, K.; Martínez-Ros, E. Green Innovation and Knowledge: The Role of Size. *Bus. Strategy Environ.* **2019**, *28*, 1045–1059.
54. Jaumotte, F.; Pain, N. *From Innovation Development to Implementation: Evidence from the Community Innovation Survey*; OECD Publishing: Paris, France, 2005.
55. Kiefer, C.P.; González, P.D.R.; Carrillo-Hermosilla, J. Drivers and barriers of eco-innovation types for sustainable transitions: A quantitative perspective. *Bus. Strategy Environ.* **2018**, *28*, 155–172. [CrossRef]
56. Junaid, M.; Zhang, Q.; Syed, M.W. Effects of sustainable supply chain integration on green innovation and firm performance. *Sustain. Prod. Consum.* **2021**, *30*, 145–157. [CrossRef]
57. Lara, A.; Caviggioli, F.; Filippini, R.; Nosella, A. Does Patenting Influence SME Sales Performance? A Quantity and Quality Analysis of Patents in Northern Italy. *Eur. J. Innov. Manag.* **2015**, *18*, 238–257.
58. Chao-Chih, H.; Chen, D. A Taxonomy of Patent Strategies in Taiwan's Small and Medium Innovative Enterprises. *Technol. Forecast. Soc. Chang.* **2015**, *92*, 84–98.

59. Zhanna, M.; Mirskikh, I. Small Innovative Enterprise: The Problems of Protection of Commercial Confi-dential Information and Know-How. *Middle East J. Sci. Res.* **2013**, *13*, 97–101.
60. Wang, W.; Liang, S.; Yu, R.; Su, Y. Theoretical Evidence for Green Innovation Driven by Multiple Major Shareholders: Empirical Evidence from Chinese Listed Companies. *Sustainability* **2022**, *14*, 4736. [CrossRef]
61. Antonioli, D.; Mazzanti, M. Towards a green economy through innovations: The role of trade union involvement. *Ecol. Econ.* **2016**, *131*, 286–299. [CrossRef]
62. Davide, A.; Borghesi, S.; Mazzanti, M. Are Regional Systems Greening the Economy? Local Spillovers, Green Innovations and Firms' Economic Performances. *Econ. Innov. New Technol.* **2016**, *25*, 692–713.
63. Aralica, Z.; Račić, D.; Radić, D. Innovation Propensity in Croatian Enterprises: Results of a Community Innovation Survey. *South East Eur. J. Econ. Bus.* **2008**, *3*, 77–88. [CrossRef]
64. Meirun, T.; Makhloufi, L.; Hassan, M.G. Environmental Outcomes of Green Entrepreneurship Harmonization. *Sustainability* **2020**, *12*, 10615. [CrossRef]
65. Albort-Morant, G.; Henseler, J.; Cepeda-Carrión, G.; Leal-Rodríguez, A.L. Potential and Realized Absorptive Capacity as Complementary Drivers of Green Product and Process Innovation Performance. *Sustainability* **2018**, *10*, 381. [CrossRef]
66. Skordoulis, M.; Kyriakopoulos, G.; Ntanos, S.; Galatsidas, S.; Arabatzis, G.; Chalikias, M.; Kalantonis, P. The Mediating Role of Firm Strategy in the Relationship between Green Entrepreneurship, Green Innovation, and Competitive Advantage: The Case of Medium and Large-Sized Firms in Greece. *Sustainability* **2022**, *14*, 3286. [CrossRef]
67. Arici, H.E.; Uysal, M. Leadership, green innovation, and green creativity: A systematic review. *Serv. Ind. J.* **2021**, *42*, 280–320. [CrossRef]
68. Fang, Z.; Razzaq, A.; Mohsin, M.; Irfan, M. Spatial spillovers and threshold effects of internet development and entrepreneurship on green innovation efficiency in China. *Technol. Soc.* **2022**, *68*, 101844. [CrossRef]
69. Van der Waal, J.W.; Thijssens, T.; Maas, K. The innovative contribution of multinational enterprises to the Sustainable Development Goals. *J. Clean. Prod.* **2021**, *285*, 125319. [CrossRef]
70. Ziegler, A. Disentangling Specific Subsets of Innovations: A Micro-Econometric Analysis of Their Determinants. In *New Developments in Eco-Innovation*; CER-ETH Center of Economic Research at ETH: Zurich, Switzerland, 2008; pp. 123–146.
71. De Marchi, V. *Cooperation toward Environmental Innovation: An Empirical Investigation*; University of Padua—Department of Economics and Management: Padua, Italy, 2010; p. 119.
72. Teresa, C.M.; García-Quevedo, J.; Martínez-Ros, E. What Are the Determinants of Investment in Environmental R&D? *Energy Policy* **2017**, *104*, 455–465.
73. Quatraro, F.; Scandura, A. Academic Inventors and the Antecedents of Green Technologies. A Regional Analysis of Italian Patent Data. *Ecol. Econ.* **2019**, *156*, 247–263. [CrossRef]
74. Cainelli, G.; Mazzanti, M. Environmental innovations in services: Manufacturing–services integration and policy transmissions. *Res. Policy* **2013**, *42*, 1595–1604. [CrossRef]
75. Rogge, K.S.; Schleich, J. Do policy mix characteristics matter for low-carbon innovation? A survey-based exploration of renewable power generation technologies in Germany. *Res. Policy* **2018**, *47*, 1639–1654. [CrossRef]