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One, Two, Three: How Many Green Patents Start Bringing Financial Benefits for Small, Medium and Large Firms?

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Abstract: This paper studies the relationship between environmental innovations and firms' financial performance from the perspective of environmental activism intensity. We explore how the number of green patents affects the financial performance of small, medium, and large firms and whether the growing number of green patents positively affects firms' financial performance. We employed a panel data sample of 1136 green innovative and 2395 non-green innovative firms from the USA and Europe and compared their financial results. The results show that small firms benefit financially only in the second year after the first green patent implementation. Medium-sized firms enjoy improved financial performance in the first two years after the implementation of one or two green patents; however, the third green patent does not anyhow improve the financial performance. Large firms gain financial benefits every year after issuing green patents regardless of the patents' quantity. Generally, the increase in financial performance is moderate in the first year, reaches the maximum in the second year, and becomes statistically insignificant in the third year after the last green patent's implementation.

Keywords: environmental innovations; financial performance; green patents; sustainable development

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1. Introduction

Growing environmental issues have become a global challenge, engaging the corporate sector as much as other sectors of society. Growing competitive pressure, technological capabilities, and environmental policies (Horbach 2008) force firms worldwide to focus on improvements in their environmental performance. In this context, environmental innovations (EIs) and their impact on firms' performance have attracted much attention from both scholars and practitioners trying to find the right balance between economic growth and firms' environmental commitment.

Numerous studies explored the influence of EI on firms' financial performance, and many of them found a positive impact (Yi et al. 2021; Liao et al. 2021; Leyva-de la Hiz et al. 2018; Vasileiou et al. 2022). However, the theoretical framework of this influence has some space for improvement. In some cases, EI brings economic value to the firm by reducing costs or improving the product, and the firms are willing to implement them without any regulations (Horbach 2008; Andries and Stephan 2019). In other cases, the firms are required to comply with minimal environmental regulation and view further environmental investing as unprofitable (Duque-Grisales et al. 2020). In both situations, EI may bring economic benefits to the firm, and in the case of patent protection, EI may help to obtain a sustainable competitive advantage (see the resource-based view (RBV) approach to strategic management (Hart 1995)). However, there is some amount of EI that is economically optimal for the firm, and exceeding this amount will lead to a decrease in

financial results. As noted by some authors (Przychodzen et al. 2020), overconcentration on EI relative to other environmental activism has negative effects on the financial performance of pioneering firms.

Therefore, it is important to collect empirical evidence to check the existence of an optimal level of EI and its factors. In this paper, we refer to EI as organizational implementations and changes focusing on the environment, with implications for firms' products, manufacturing processes, and marketing, with different degrees of novelty (Angelo et al. 2012). We may note that firms' engagement in EI differs tremendously even within the same industry. One important firm-level characteristic that heavily affects its environmental activism is the size of the firm. Small and large firms substantially differ in their strategic motivation, management practices, and access to resources (Lin et al. 2019), resulting in huge differences in their environmental activities and obtained financial results (Andries and Stephan 2019).

Firms of various sizes have different cost efficiency when it comes to EI development. Small firms tend to focus on one product or service, so it may be easier for them to develop EI related to one narrow area rather than a range of EIs of various environmental or technological natures. Larger firms are usually more diversified, both horizontally and vertically, so they have higher chances of being involved in various technological and environmental issues where conceptual ideas for EI may be naturally generated and developed. Moreover, large firms have more potential to enjoy slack resources. George (2005) defines slack as "potentially utilizable resources that can be diverted or redeployed for the achievement of organizational goals". In fact, reversed causality may take place here; slack resources proved to be positively associated with a higher number of innovations, which, in their turn, may result in better competitive advantages (Aragon-Correa and Hiz 2015) and improved financial performance. Overall, we may expect that resource constraints and narrow focus make a lower number of EI more cost-effective for small firms than for larger firms.

The mechanisms that drive the financial benefits as a result of EI introduction may also be different for firms of various sizes. Both small and large companies can enjoy cost reduction and marketing benefits caused by EI introduction, but larger firms are more likely to engage in long-lasting large-scale environmental projects entailing resource saving and increasing customer loyalty from a diversity of EI. Small firms usually focus on a particular technology or closely follow their target audience's needs to achieve financial benefits, which apparently limits the scope of the EI, so they may benefit only from EI related to a particular area. Obtaining EI outside their scope is related to additional expenditures that might never be made up and just weaken the firm (Andries and Stephan 2019).

The time period when EI may start bringing first financial benefits may also be different for small and large firms. Previous studies demonstrate that in many cases, EI introduction may have a delayed financial effect (Marín-Vinuesa et al. 2018; Qing et al. 2022). Some studies explore how different EI types impact the short-term and long-term financial performance of the firms (Ghisetti and Rennings 2014). However, the question of the timeframe when firms of various sizes may start getting financial benefits from their first, second, and consequent EI is still underexplored. This timeframe is directly associated with the mechanisms of how small and large firms may improve financial performance as a result of EI introduction. Small firms are more flexible, reactive, and, in general, have less bureaucracy (Pinget et al. 2015). Therefore, they might quicker introduce EI to solve small ad-hoc problems, i.e., emission reduction or environmentally friendly package development. Still, being a complex process, the EI introduction may imply a series of technological, production, and marketing changes (Vasileiou et al. 2022), and considering the resource constraints typical for small firms, the financial benefits would hardly outweigh the expenditures very soon after the EI introduction. Moreover, this natural time lag between the EI introduction and the first potential financial benefits provides an additional argument for small firms to introduce EI more seldom unless there is severe institutional or legal pressure. Large firms have the resources to implement successful innovations on a

larger scale and get profits through better access to large markets (Aguilar-Fernández and Otegi-Olaso 2018). Their large-scale environmental projects may take quite a long time; however, having a larger influence and access to media, larger companies may start yielding the first financial results long before the whole process of EI introduction is finished, i.e., by increasing their customers' loyalty.

Unlike previous studies, this paper aims to explore the relationship between EI and financial performance from the perspective of the intensity of environmental activism of small, medium, and large firms measured by green patents. Following (Ghisetti and Rennings 2014), we contribute to the debate on when it pays to be green by differentiating how the number of EI affects the financial performance of small, medium, and large firms and, specifically, analyze the impact of the first, the second, and the third EI.

We employed a panel data sample of 1136 green innovative firms (firms that were involved in tangible green developments (Marcus and Fremeth 2009) and obtained green patents in 2013–2018) and 2395 non-green innovative firms (without green patents in 2010–2018) from the USA and Europe. We matched each green innovative firm with non-green innovative firms of the same size and checked that the matched firms had no green patents during the periods of analysis. Following Aguilera-Caracuel and Ortiz-de-Mandojana (2013), we directly compared the financial results of green innovative firms and the matched firms. Our results indicate that different numbers of green patents bring different financial results for small, medium, and large firms. We found that, on average, small firms benefit financially only in the second year after the first green patent introduction. The second and further green patents lead to a decrease in financial performance compared to non-green innovative firms. Medium-sized firms usually enjoy improved financial performance in the first two years after the introduction of one or two green patents; however, the third green patent does not anyhow improve the financial performance. Large firms gain financial benefits every year after issuing green patents regardless of the patents' quantity.

One of the major contributions of this paper is that it jointly considers the firm size, intensity of environmental activism, and the time period after the latest EI introduction as potential moderators of the relationship between EI and financial performance. Our study expands the current understanding of how EI affects firms' financial performance by providing an important context of this relationship that can be further adapted by policymakers and business owners in making decisions and planning their environmental activities.

2. Materials and Methods

Following previous studies (Leyva-de la Hiz et al. 2018; Hoang et al. 2020; Aguilera-Caracuel and Ortiz-de-Mandojana 2013), we used green patents to measure firms' environmental activism. Green patents as an EI measure have several advantages: measurability, comparability among firms from different markets, and broad usage in the relevant literature (Hoang et al. 2020). Since patents contain standardized information about new technologies and ideas, they are considered to be the most important indicator of innovation (Frietsch and Grupp 2006). Moreover, it is important that innovations are protected legally and by other mechanisms as it affects the extent to which firms profit from innovations (Frietsch and Grupp 2006).

To measure financial performance, we used return on assets (ROA) as the ratio between the annual profits and the firm's total assets value. ROA is widely used for its reliability in the literature dedicated to EI and serves as a proxy for the firm's financial performance (Duque-Grisales et al. 2020; Aguilera-Caracuel and Ortiz-de-Mandojana 2013; Wu 2017; Xie et al. 2019).

We collected data on the total assets and net income of European (87.9%) and North American (12.1%) firms in 2014–2019 from the Orbis database (sample A contains 3531 firms). Table 1 contains information on the distribution of these firms by size for each country. We used the widespread Alpha-2 codes (ISO 3166) for countries' designation.

Table 1. The firms' sample distribution by countries.

Firms' Size	Country												
	AT	***BA***	***BE***	***BG***	***BM***	***CA***	***CH***	***CZ***	***DE***	***DK***	***EE***	***ES***	***FI***
Small	0/0	0/1	6/47	5/8	0/0	0/0	0/1	11/11	9/22	0/0	0/3	66/39	11/12
Middle	0/0	0/1	3/27	0/0	0/1	0/0	0/0	23/11	73/58	0/0	0/0	18/28	6/13
Large	6/11	0/0	8/38	0/0	3/29	1/5	2/33	8/7	126/233	3/6	1/0	14/47	19/24
Total	17	2	129	13	33	6	36	71	521	9	4	212	85
Firms' Size	**Country**												
	FR	***GB***	***GR***	***HR***	***HU***	***IE***	***IT***	***LI***	***LT***	***LU***	***LV***	***NL***	***NO***
Small	7/17	19/65	2/1	2/1	0/17	2/1	141/100	0/0	1/0	0/0	2/4	28/26	0/0
Middle	8/10	54/82	0/0	3/0	0/14	1/2	60/42	0/0	2/3	0/0	0/0	9/17	0/0
Large	19/48	75/126	0/2	0/0	0/4	4/9	51/89	1/0	2/1	0/7	0/0	12/52	2/6
Total	109	421	5	6	35	19	483	1	9	7	6	144	8
Firms' Size	**Country**												
	PL	***PT***	***RO***	***RS***	***RU***	***SE***	***SI***	***SK***	***TR***	***UA***	***US***		
Small	1/3	2/6	14/9	0/0	11/192	32/56	1/16	6/2	0/0	0/4	2/3		
Middle	0/4	2/4	2/2	0/2	3/104	8/21	1/4	3/3	0/0	0/5	2/6		
Large	0/10	1/2	2/2	0/0	2/128	14/55	0/2	1/0	2/4	0/5	95/279		
Total	18	17	31	2	440	186	24	15	6	14	387		

Most of the studied firms in the sample are located in Belgium (129), Germany (521), Spain (212), France (109), Great Britain (421), Italy (483), Netherlands (144), Russia (440), Sweden (186), the USA (387). In Table 1, each cell contains two numbers divided by a slash; the first is the number of green firms, and the second is the number of firms without green patents. If a firm's size changed within the reviewed time period, then the median size was taken as its size along this time interval (Table 1).

We used the WIPO database to collect the sample of green innovative firms with at least one green patent published in 2013–2018 and non-green innovative firms with no green patents published in 2010–2018 (sample B contains 16,674 patents records). We specifically focused on the patents that were included in the WIPO category "24—environmental technology". In this paper, we use the patents' priority date as the date closest to the moment of environmental innovation introduction. In contrast, the publishing date cannot serve as a reliable indicator of the timing of ecological innovation; it can take more than a year from filing to the publication of a patent. For the patents in sample A in the article, the median time between publishing and priority date was equal to (1.79 ± 0.07) years.

We formed the intersection of these two samples as follows. First, public authorities/states/governments and firms with no recent financial data were excluded from sample B. After that, we matched the firms' names from sample A and sample B to find reliable intersections. To do that, based on (He et al. 2018; Raffo and Lhuillery 2009; Lee et al. 1999; Graham et al. 2018), we developed the following advanced procedure.

1. We turned the firms' names in samples A and B into the uppercase text;
2. We removed "the" and non-text characters such as spaces, dots, commas, dots with commas, hyphens, single and double quotes, parentheses, etc. We replaced the symbol "&" with "AND";
3. We replaced all widely used abbreviations with the common reduced form: "INCORPORATED" to "INC", "OPENED JOINT STOCK COMPANY" to "OSJC", "PUBLIC LIMITED COMPANY" to "PLC", "LIMITED LIABILITY COMPANY" to "LLC", "LIMITED" to "LTD", "COMPANY" to "CO". The order of these replacements mattered;
4. We deleted all abbreviations from the endings of firms' names in samples A and B ("PUBL", "AB", "AG", "LTD", "INC", "CO", "LLC", "PLC", "OJSC") and, after that, from their beginnings ("OJSC", "LLC", "PLC");
5. For the non-trivial errors and variations in firms' names (such as typos), we calculated the Levenstein distance between all pairs of text strings representing firms' names included in sample A and sample B. For each pair, we normalized the obtained value following (Lambert et al. 1999). We interpreted the firms' names as coincidental if the normalized distance was lower than the pre-determined threshold based on the statistic of typos occurrence in economic databases.

The threshold value was determined as follows. After completing steps 1–5, the average length of a firm's name was calculated, and it equaled 16.1 symbols. Following (Pollock and Zamora 1983) and (Damerau 1964), the typical errors in firms' names do not exceed 1–2 symbols (1-symbol typos were detected in 90–96% of cases in full-scale studies and at least 80% in small-scale studies). So, we set the threshold as 0.1.

The described procedure helped to increase the depth of the dataset's match and obtain the final accurate dataset. As a result, we obtained a sample of 1136 firms with green patents and 2395 firms without green patents.

The ROA distribution values turned out to be significantly different from the normal one (Shapiro-Francia and Shapiro–Wilk tests both reject the hypothesis on normality, p-value $< 10^{-30}$). To detect the outliers, we used three approaches: whiskers boxplot (Tukey 1977) to find the values lying outside the interval J covering 99% of the population; the sequential Grubbs' test based on estimating z-score (Adikaram et al. 2015) for the p-value equal to 0.01.

We also applied the DBSCAN algorithm (Ester et al. 1996) to detect the outliers (the parameters of the algorithm were equal to $n_{\min} = 0.5 \cdot n$ and $\varepsilon = 1.25 \cdot \sigma$, where $n_{\min}$ is the minimum number of points in the clustered data that are allowed to form a single cluster; n is the number of points in data to be processed; ε is the magnitude of the neighborhood of a point to connect points in one cluster; σ is a standard deviation of the population to be analyzed for outliers, such parameters correspond to the normally distributed population to detecting 1% of the data to be outliers).

If an ROA value was recognized as an outlier by at least two of the mentioned approaches, then the corresponding data were removed from further calculations.

We followed the OECD classification to identify the firms' size (Enterprises by Business Size 2021): 250 or more employers in large firms, 50 to 249 employees in medium-sized, and less than 50 in small firms.

In our study, we adopted the principles of PSM methodology and partly followed the leading papers in this research area that applied the direct comparison (Aguilera-Caracuel and Ortiz-de-Mandojana 2013; Przychodzen and Przychodzen 2015; Tugores and García 2015; Forsman 2013; Fernando et al. 2010).

We divided the initial sample into subgroups for direct comparison of green firms and firms without green patents under the same or close to other conditions. We considered the firm's size and the number of green patents introduced over the last few years as control variables. Firms' age in the sample was greater than at least 6 years.

The research question was mathematically formulated as follows. Let $P_k(n)$ be the probability that the obtainment of n green patents on average leads to an improved firm's financial performance measured by ROA, compared to the financial performance of the firms without green patents after k years since the latest patent's introduction. Let $n_{\max}(k)$ be the number of patents that maximizes $P_k(n)$: $n_{\max}(k) = \underset{n}{\operatorname{argmax}} P_k(n)$. We studied these values for small, medium, and large firms correspondingly.

To study the $n_{\max}$ value, we applied the following procedures based on the direct statistical comparison of ROA for 2014–2018 for the two groups of firms: green innovative firms and the matched ones.

1. Paired one-sided t-test for the null hypothesis stating that the ROA of the firms with n green patents on average is larger than the median ROA of firms without green patents after k years since the latest green patent has been introduced:

$$E[\mathrm{ROA}_k^{\mathrm{eco}}(n)] > med[\mathrm{ROA}_k^{\mathrm{conv}}],$$

where E is the mathematical expectation, med is the median value, and ROA^{eco} and ROA^{conv} are ROA values for green innovative firms and non-green innovative firms correspondingly;

2. Paired one-sided sign test for the null hypothesis stating that the ROA of the firms with n green patents is more often larger than the median ROA of the firms without green patents after k years since the latest green patent has been introduced:

$$med[\mathrm{ROA}_k^{\mathrm{eco}}(n) - med[\mathrm{ROA}_k^{\mathrm{conv}}]] > 0;$$

3. The probability estimate

$$q = \mathrm{Prob}(\mathrm{ROA}_k^{\mathrm{eco}}(n) > med[\mathrm{ROA}_k^{\mathrm{conv}}])$$

that the ROA of the firms with n green patents will be larger than the median ROA of the firms without green patents after k years since the latest patent was issued.

To test the robustness of the results, we processed the original ROA data as is and, after outliers' removal, applied the procedure mentioned above (values lying outside the interval covering 99% of the population) and found no statistically significant differences.

The descriptive statistics—in-sample distributions for firms-green patent holders and firms without green patents—are presented in Tables 2 and 3. Tables contain the values of the following sample statistical characteristics: mean value (mean), median value (med), standard deviation (s), and bounds of the confidence interval for confidence probability equal to 90% (formed by 5% and 95% quantiles). Again, if a firm's size changed within the reviewed time period, then the median size was taken as its size along this time interval in Tables 2 and 3.

Table 2. Descriptive statistics for green firms' total sample (1136 firms).

	Small Firms (381)				Medium Firms (281)				Large Firms (474)			
	Mean	**Med**	**s**	**90% CI**	**Mean**	**Med**	**s**	**90% CI**	**Mean**	**Med**	**s**	**90% CI**
Patents number	7.92	4	16.17	[1.00, 26.5]	9.63	4	17.47	[1.00, 35.9]	51.64	7	193.4	[1.00, 206.8]
ROA in 2012	0.061	0.036	0.253	[−0.39, 0.81]	0.048	0.048	0.087	[−0.17, 0.22]	0.045	0.043	0.061	[−0.09, 0.17]
ROA in 2013	0.044	0.028	0.297	[−0.56, 0.66]	0.048	0.053	0.083	[−0.17, 0.22]	0.052	0.046	0.058	[−0.06, 0.17]
ROA in 2014	0.021	0.023	0.271	[−0.61, 0.48]	0.046	0.041	0.081	[−0.13, 0.20]	0.052	0.048	0.054	[−0.06, 0.16]
ROA in 2015	0.049	0.024	0.339	[−0.46, 0.58]	0.048	0.039	0.084	[−0.13, 0.24]	0.046	0.044	0.057	[−0.08, 0.16]
ROA in 2016	0.022	0.027	0.300	[−0.57, 0.53]	0.050	0.040	0.085	[−0.12, 0.24]	0.047	0.045	0.060	[−0.08, 0.17]
ROA in 2017	0.024	0.018	0.206	[−0.47, 0.44]	0.047	0.038	0.081	[−0.12, 0.21]	0.047	0.042	0.054	[−0.07, 0.16]
ROA in 2018	0.020	0.013	0.235	[−0.42, 0.43]	0.048	0.039	0.088	[−0.12, 0.23]	0.046	0.044	0.060	[−0.08, 0.17]
ROA in 2019	0.059	0.013	0.327	[−0.41, 0.98]	0.071	0.037	0.136	[−0.14, 0.47]	0.067	0.048	0.120	[−0.10, 0.43]

Table 3. Descriptive statistics for the total sample of the firms without green patents (2395 firms).

	Small Firms (620)				Medium Firms (459)				Large Firms (1316)			
	Mean	**Med**	**s**	**90% CI**	**Mean**	**Med**	**s**	**90% CI**	**Mean**	**Med**	**s**	**90% CI**
Patents number	0	0	0	[0, 0]	0	0	0	[0, 0]	0	0	0	[0, 0]
ROA in 2012	0.045	0.027	0.174	[−0.34, 0.43]	0.035	0.030	0.095	[−0.21, 0.21]	0.035	0.030	0.052	[−0.08, 0.15]
ROA in 2013	0.036	0.025	0.177	[−0.41, 0.39]	0.037	0.030	0.102	[−0.18, 0.25]	0.039	0.035	0.051	[−0.07, 0.15]
ROA in 2014	0.053	0.030	0.154	[−0.27, 0.44]	0.038	0.032	0.094	[−0.19, 0.24]	0.041	0.036	0.047	[−0.04, 0.15]
ROA in 2015	0.043	0.026	0.143	[−0.27, 0.38]	0.038	0.034	0.098	[−0.20, 0.22]	0.038	0.033	0.049	[−0.06, 0.14]

Table 3. *Cont.*

	Small Firms (620)				Medium Firms (459)				Large Firms (1316)			
	Mean	**Med**	**s**	**90% CI**	**Mean**	**Med**	**s**	**90% CI**	**Mean**	**Med**	**s**	**90% CI**
ROA in 2016	0.043	0.024	0.157	[−0.32, 0.41]	0.038	0.034	0.095	[−0.20, 0.22]	0.037	0.032	0.051	[−0.07, 0.15]
ROA in 2017	0.033	0.023	0.176	[−0.38, 0.45]	0.044	0.037	0.098	[−0.21, 0.23]	0.040	0.033	0.046	[−0.04, 0.14]
ROA in 2018	0.040	0.023	0.146	[−0.31, 0.41]	0.033	0.035	0.107	[−0.23, 0.20]	0.040	0.033	0.048	[−0.05, 0.15]
ROA in 2019	0.080	0.025	0.223	[−0.22, 0.78]	0.053	0.035	0.120	[−0.19, 0.34]	0.045	0.038	0.059	[−0.07, 0.19]

3. Results

We performed the abovementioned tests for $n = 1, 2$, and 3 green patents for $k = 1, 2, 3$, and 4 years. The firms' sizes were taken exactly for the specified year (both for the green innovative firms and non-green innovative firms).

The results are presented in Tables 4–7, which contain corresponding p-values. Table 8 shows the samples' sizes in the form (x/y), where x is the sample size for firms with green patents and y—for firms without green patents. We colored p-values less than 0.05 with green, from 0.05 to 0.15 with yellow, and greater than 0.95 with red.

Table 4. The tests' p-values for $k = 1$.

Firms' Size	**1 Green Patent**			**2 Green Patents**			**3 Green Patents**		
	***t*-Test**	**Signtest**	$1 - q$	***t*-Test**	**Signtest**	$1 - q$	***t*-Test**	**Signtest**	$1 - q$
Small	0.169	0.072	0.332	0.406	0.935	0.966	0.581	0.738	0.738
Medium	0.024	0.025	0.025	0.095	0.443	0.443	0.902	0.837	0.837
Large	0.204	0.008	0.008	0.197	0.076	0.076	0.004	0.010	0.010

p-values less than 0.05 are colored with green, from 0.05 to 0.15 with yellow, and greater than 0.95 with red.

Table 5. The tests' p-values for $k = 2$.

Firms' Size	**1 Green Patent**			**2 Green Patents**			**3 Green Patents**		
	***t*-Test**	**Signtest**	$1 - q$	***t*-Test**	**Signtest**	$1 - q$	***t*-Test**	**signtest**	$1 - q$
Small	0.042	0.133	0.676	0.560	0.993	0.997	0.137	0.500	0.500
Middle	0.008	0.090	0.090	0.066	0.122	0.122	0.263	0.581	0.581
Large	0.236	0.124	0.124	0.037	0.111	0.111	0.030	0.039	0.039

p-values less than 0.05 are colored with green, from 0.05 to 0.15 with yellow, and greater than 0.95 with red.

Table 6. The tests' p-values for $k = 3$.

Firms' Size	**1 Green Patent**			**2 Green Patents**			**3 Green Patents**		
	***t*-Test**	**Signtest**	$1 - q$	***t*-Test**	**Signtest**	$1 - q$	***t*-Test**	**Signtest**	$1 - q$
Small	0.151	0.806	0.962	0.802	0.996	0.999	0.558	0.941	0.941
Middle	0.062	0.304	0.304	0.739	0.364	0.364	0.061	0.584	0.584
Large	0.044	0.022	0.022	0.052	0.040	0.061	0.412	0.598	0.598

p-values less than 0.05 are colored with green, from 0.05 to 0.15 with yellow, and greater than 0.95 with red.

Table 7. The tests' p-values for $k = 4$.

Firms' Size	**1 Green Patent**			**2 Green Patents**			**3 Green Patents**		
	***t*-Test**	**Signtest**	$1 - q$	***t*-Test**	**Signtest**	$1 - q$	***t*-Test**	**Signtest**	$1 - q$
Small	0.589	0.656	0.967	0.156	0.785	0.948	0.714	0.887	0.927
Middle	0.122	0.623	0.806	0.606	0.708	0.708	0.574	0.788	0.788
Large	0.525	0.252	0.252	0.510	0.788	0.788	0.627	0.500	0.500

p-values less than 0.05 are colored with green, from 0.05 to 0.15 with yellow, and greater than 0.95 with red.

Table 8. Samples' sizes for tests which results are in Tables 4–7.

Firms' Size	$k = 1$			$k = 2$			$k = 3$			$k = 4$		
	$n = 1$	$n = 2$	$n = 3$	$n = 1$	$n = 2$	$n = 3$	$n = 1$	$n = 2$	$n = 3$	$n = 1$	$n = 2$	$n = 3$
Small	17/508	17/508	74/489	13/485	67/485	17/485	12/502	54/502	15/502	6/474	40/474	11/474
Middle	17/428	17/428	48/415	14/426	36/426	24/426	15/426	33/426	22/426	10/411	30/411	14/411
Large	30/1236	30/1236	49/1268	27/1261	43/1261	21/1261	25/1244	33/1244	16/1244	20/1212	25/1212	13/1212

4. Discussion

Environmental problems aggravation has spurred extensive research on EI and their financial implications. An explicit understanding of how EI impacts firms' financial performance is essential as it draws more firms to EI activities and helps to design policies to ensure accurate support. However, the empirical evidence of EI financial implications shows divergent results, so this paper aimed to provide new insights into this research by adding firms' size and the length of the period after EI introduction to the context of the relationship between environmental innovations.

The design of the study also made it possible to see the difference in financial results of green firms with different numbers of green patents. For linear-case regression—a popular instrument of analysis—this dependency is usually described as $\Delta FP_t \sim \alpha \cdot GP_{t-1}$, where FP is the financial performance of a green firm, ΔFP_t is its increase for the year t, GP is the number of green patents, α is a sensitivity coefficient independent from any control and dependent variables. Such models can only show that with every subsequent green patent, firms experience permanent additional financial performance increase (if $\alpha > 0$) or decrease (if $\alpha < 0$), and no trend changing is allowed.

In our study, we constructed the dependency in a more generalized and complicated way: $\Delta FP_t \sim f(Size_{t-1}, GP_{t-1})$, where f is a non-constant function of the green patents number and firms' size. Using this approach, we separately investigated the influence of each patent instead of the averaged impact estimated in regression models and found that the larger green patents number is not generally associated with larger financial benefits for small firms, medium-sized firms, and even large enterprises. This original approach is one of the contributions of our study.

To ensure the sensitivity of our analysis, we tested the financial performance (ROA) of green firms against the median value of the ROA of firms without green patents. Using the median value is better than using mean values because of greater robustness and no sensitivity to outliers. This allowed us to indicate whether the financial results of green firms that met certain conditions exceeded the financial results of half of the firms without green patents in the selected countries. The application of this approach helped to mitigate the statistical uncertainty related to the green firms' sample sizes and shed light on the peculiarities of the relationship between the number of green patents and averaged financial benefits.

Our research demonstrated that outliers' removal did not substantially affect the final results of the study. We also see that for the firms without green patents, the difference between the mean and median of the obtained ROA values distributions does not exceed 0.15 (small firms), 0.25 (medium-sized firms), and 0.16 (large firms) of the population standard deviation for any year from the considered time period. This is much less than the statistical uncertainty caused by the relatively small size of the samples in Table 8. Therefore, our results are determined by the relation between financial performance increase and green patents number but not by the biases from the applied statistical approach.

The results presented in Table 4 were calculated for the first year after the latest green patent introduction. For small firms, the financial effect of EI introduction is quite ambiguous, even in the case of only one green patent introduction. Apparently, substantial costs on green R&D usually come as a burden for a small firm, and the expenses on green patent implementation that follow green patent obtaining are not covered by the financial benefits gained next year. Additionally, in contrast to large firms, small firms may have higher marginal costs as they cannot enjoy economies of scale (Khanna 2001). This result corroborates (Andries and Stephan 2019) in the part that "smaller firms reap fewer financial benefits from environmental innovation than their larger counterparts".

For medium-sized firms, the first green patent, on average, leads to an increased ROA in the first year after the green patent introduction compared to medium-sized firms without green patents. So, for them, the generated financial benefits exceed the costs of green R&D. Larger small and medium firms (SMEs) are more financially stable, enjoy better access to human resources (Pinget et al. 2015), and usually have a wider market presence. In

the case of two green patents, we observe ambiguous results; there are no explicit financial implications in the first year after the second green patent's introduction. When three green patents are introduced, medium-sized firms experience decreased financial performance due to the high development and introduction costs.

Finally, large firms enjoy improved financial performance regardless of the number of implemented green patents. Every subsequent green patent does not make any substantial difference when it comes to large firms' financial performance.

Table 5 shows the results calculated for the second year after the latest green patent introduction. Small firms benefit financially only when one green patent is introduced. The second and further green patent introduction is associated with a decrease in financial performance due to financial constraints. For medium-sized firms, the introduction of up to two green patents in the second year after the latest green patent's introduction leads to improved financial performance, yet the introduction of the third green patent most likely causes a decrease in financial performance. The situation with large firms does not change: a green patent introduction is associated with improved financial performance regardless of the green patent quantity.

These results comply with (Bermúdez-Edo et al. 2016), who suggested that a greater number of patented EI does not increase firm performance. They are also in line with (Przychodzen et al. 2020), who showed that an increasing share of green patents in the total number of patents negatively influences current financial performance, and there are positive lagged financial performance gains from being active in the field of green innovations (one- and two-year lagged financial performance effects).

Given the financial constraints and lack of resources, small firms are more likely to obtain focused EI, i.e., innovations that invest in well-known technologies rather than unrelated technologies that require much experimentation—diversified EI (Leyva-de la Hiz et al. 2018). If SMEs obtain more than two green patents, their EI naturally becomes more diversified, provided that SMEs usually focus on one narrow area. This requires more resources for R&D but, at the same time, offers less predictability of financial success. In this case, SMEs become more financially vulnerable, and, obviously, only large firms can afford experimentations with diversified EI, not worrying about their financial performance.

Table 6 shows the results calculated for the third year after the latest green patent introduction. In the third year, the firms' financial implications of EI start shrinking compared to firms with no green patents. The results for the fourth year presented in Table 7 support this tendency. Financial implications in absolute numbers are still higher for the firms with green patents, but the probability of gaining more is close to the probability of gaining less. This fact might serve as a check for our study design; we measured the number of green patents only within the specified time period and controlled that no patents were implemented in the previous three years. If any green patents were implemented before this time, their financial implications could not affect our results.

The presented results show the following averaged estimates of $n_{\max}(k)$. For small firms, $n_{\max}(1) = 0$; $n_{\max}(2) = 1$; $n_{\max}(3) = 0$. For medium-sized firms, $n_{\max}(1) = 1$; $n_{\max}(2) = 1 \div 2$; and $n_{\max}(3) = 0 \div 1$. For large firms, $n_{\max}(1) \leq 3$; $n_{\max}(2) \leq 3$; and $n_{\max}(3) \leq 2$.

These findings empirically extend the conclusions of (Appio et al. 2019), who demonstrated that "profitability increases until a certain level of patent portfolio diversity reaches a maximum and then decreases". They are also in line with (Leyva-de la Hiz and Bolívar-Ramos 2022) in the part that overemphasis on environmental innovations may be detrimental to firm performance.

The results demonstrate that the positive effect of EI on financial performance is not only lagged from the moment of EI introduction but also limited in time as in the fourth year after green patents introduction, the difference in ROA between green innovative and non-green innovative firms ceases to be attributed to green patents existence regardless of green patents quantity. Successful innovations may be "picked up" by other players in the market and implemented by them, and thereby, the positive difference in financial

performance that green innovative firms enjoy may be offset as other firms also start taking advantage of the benefits brought by this EI.

The results of this study also suggest that the assessment of how EI affects firms' financial performance should consider the size of the firms together with the length of the period after the latest green patent introduction. Moreover, it is important to consider the ratio of small, medium, and large firms in the sample to avoid disproportions and, thereby, biased results. One of the following options might be followed. The first option implies composing the sample of small, medium-sized, and large firms in the same proportion to avoid prevailing the one-size group results. The second option takes into account the industry of the firms in the sample. It implies that firms' sizes in the sample should correspond to the natural distribution that takes place in a real market or industry so that the final integral result for the whole market or industry is averaged in terms of the firm's size in the right way. For example, if the sizes of the firms in the real market are distributed as 10% for large, 20% for medium-sized, and 70% for small, the sample should be composed correspondingly. The third option implies studying the effects of each size group separately.

5. Conclusions

In an attempt to disentangle the ambiguity of the empirical results of how environmental innovations affect firms' financial performance, this research studies this relationship from the perspective of firms' size, the number of EI, and the length of the period after the latest EI introduction. Firms of different sizes are different in many aspects, and we demonstrate one additional important dimension; the financial effects of the implementation of different numbers of green patents are different for large, middle, and small firms. The application of the microeconomic methodology is an important area of improvement in the field of EI research, which quite often lacks microfoundations for theoretical comprehension of the studied phenomena.

Our findings demonstrate that when assessing the effect of EI on firms' financial performance, it is crucial to consider the size of the firm together with the number of EI and the length of the period after the latest EI introduction. Moreover, our research underscores the importance of considering the ratio of small, medium-sized, and large firms in the studies' samples to avoid disproportions and, thereby, biased results.

The results indicate that, on average, for small firms, the impact of EI on financial performance is generally negative, and only the introduction of one green patent in three years can be associated with some financial benefits in the second year after this patent's introduction.

Medium-sized firms observe an increase in financial performance in the first two years after the introduction of one or two green patents. The third green patent does not anyhow improve financial performance. Large firms, on average, gain financial benefits every year after green patents' introduction, regardless of the patents' quantity.

Generally, the increase in financial performance is normally moderate in the first year after the latest green patent introduction. It reaches the maximum in the second year and becomes statistically insignificant in the third year.

5.1. Theoretical Contributions

The theoretical contributions of this paper are as follows. First, this study has provided new insights into the relationship between EI and financial performance by showing the importance of additional contextualization when assessing this relationship. Second, our research provides nuanced empirical evidence to RBV by bringing in the quantity of EI linked with the firms' size as important conditions of the positive impact of EI on firms' financial performance. Third, for the first time, this paper empirically studied how the length of the period after the latest EI introduction affects financial performance with regard to the firm size. Overall, our work expands the boundary conditions of EI research.

Additionally, this research provides several methodological contributions related to data processing in the studies in this field. First, we developed a special algorithm to

connect firms' names in databases of patents and financial data. Second, the study presents the combined procedure to detect outliers. Third, we proposed to make conclusions on the results using the set of statistical tests; it is recommended to use not only measures such as average treatment effect that deals with absolute values but also additionally apply the tests based on probabilities and ratios comparison.

5.2. Practical Implications

This study offers several practical implications. First, firms can more precisely plan their environmental activities considering their firm's size and the quantity of the upcoming EI to better balance environmental activism and economic development. Second, our research vividly demonstrates the importance of a differentiated approach toward firms of various sizes in terms of support and stimulation of EI introduction. Policymakers can pay special attention to SMEs' support as, on the one hand, smaller firms are less eager to involve in environmental activities due to financial constraints, lack of resources, and extended payback period on investment in EI, and, on the other hand, they are responsible for approximately 64% of all industrial pollution (Pinget et al. 2015). A clear understanding of how and when firms of various sizes can enjoy the positive financial effect of their EI helps to accurately design appropriate targeted policy.

5.3. Limitations

Like any other study, this study has some limitations that provide opportunities for future research. First, we measured environmental activism by green patents, so the other types of firms' EI were not considered. Future research could focus on more objective measures that would reflect the effect of overall EI.

Second, considering data availability, our firms' sample was limited to European and North American firms. The inclusion of more parts of the world in the analysis would extend theoretical development and empirical design. Our research methods could be extended to an interesting cross-country comparison. Assuming that, ceteris paribus, in the countries with advanced environmental culture and regulation, green patents might bring more marginal benefits because green activities are expected from companies and brands, and it is easier to conduct them because regulation is friendly to green investments, we may expect that the inflection point where the next green patent becomes unprofitable should be located closer to a larger number of patents. However, at the same time, we may assume that in these countries, the majority of the firms are more involved in green innovations, and some additional green patents may have a limited value for the market and for the firm. These opposing assumptions create a theoretical intrigue that may be resolved based on future research.

Third, future research could add indicators of long-term corporate financial performance, such as Tobin's Q, market value (MV), and price-to-earnings ratio (P/E).

Furthermore, future research could include the environmental status of a firm in the analysis to see if, for environmental companies, the inflection point where the next green patent becomes unprofitable is located closer to a larger number of patents.

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