Design and environmental technologies: Does ‘green-matching’ actually help?[χ]

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Abstract

This paper investigates whether a green kind of design helps firms increase their capabilities for inventing in the environmental domain and whether it does so more than ‘standard’ design. It also investigates whether the effect of ‘green-matching’ between new design and technologies is conditional on firms’ innovative capabilities, as reflected by their R&D expenditure. We address these research questions with respect to the world’s top R&D investors, looking at their intellectual property rights at the United States Patent and Trademark Office (USPTO) and proposing an original textual identification of green designs and trademarks. We find that green design increases environmental inventions by top R&D investors, and to a greater extent than non-environmental ones. Standard design also stimulates environmental inventions, but to a lesser extent than green design. The ‘green-matching’ actually helps, but internal innovative capabilities are required to make it effective: a green-tech ‘prize’ emerges from green design, but only once a minimum threshold of R&D expenditure has been reached.

Keywords: eco-innovation; eco-design; green technologies; green-oriented design; R&D.

JEL codes: O30, O13, O44.

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1. Introduction

Designing new products and production processes by considering their impact on the environment — a practice frequently called ‘eco-design’ — has become a cornerstone of the new policy course towards environmental sustainability and the circular economy (EC, 2015; European Environmental Bureau, 2015). Shaping the functionality of product architectures and modules, and intervening in their aesthetic and symbolic meaning through design have been identified as crucial leverage through which firms can render their products more easily repairable and longer-lasting, make their materials and components easier to re-use, refurbish, and recycle, and reduce the use of hazardous substances (see Tukker et al., 2001).

Existing research has mainly concentrated on the managerial aspects of eco-design and, above all, on production and engineering techniques through which design can be successfully integrated into new product development (e.g. Johansson, 2002; Knight and Jenkins, 2009; Yang and Chen, 2011; Santolaria et al., 2011). Important knowledge has been obtained from these works, mainly with the help of in-depth case-studies about individual projects and/or specific products. More systematic evidence on the topic has been added by a related stream of research on environmental and eco-innovations (EI),[1] which makes extensive use of econometric analysis to investigate their determinants at the firm level (for a review, see Ghisetti and Pontoni, 2015). In these studies, design emerges as a possible driver of innovative outcomes with a favourable environmental impact. In particular, significant correlations have been found between a firms’ engagement in design activities, in terms of investments and placement in their business model, and their EI capacity (e.g. Marzucchi and Montresor, 2017; Ghisetti and Montresor, 2019).

This last stream of research suggests that through design activities, firms can acquire capabilities not only to develop new technologies but also to ‘direct’ them in the environmental domain. This is a potentially important suggestion that deserves more analysis in order to: i) identify the working mechanisms and nature of these green-tech-enabling design capabilities, and; ii) ascertain the actual extent to which they can favour firms’ environmental technologies. These are the two gaps the present paper aims to fill.

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[1] On the not trivial difference between environmental and eco-innovation, see Ekins (2010) and Huppes et al. (2008). Out of the two, in the following we stick to the former. Unlike eco-innovations, environmental ones do not extend to the business implications of green inventions, which we are not capable of addressing in this paper.

As far as the first gap is concerned, an important issue to address is whether firms' design capabilities can be complementary to their capacity to introduce technological inventions of an environmental nature, confirming and refining what recent studies have shown with respect to innovation in general (e.g. Montresor and Vezzani, 2020). In the 'regulatory-technology push/demand-pull approach' to EI (Horbach et al., 2012), design capabilities have been mainly accounted for as capabilities to implement environmental regulations that insist on design. In turn, these regulation-related capabilities have been mainly searched for and found in the R&D and engineering activities/departments of firms, where eco-design practices are implemented in the first place. Design capabilities as such, that is, capabilities to introduce and implement novel design attributes — pertaining to product ergonomics, form, aesthetics, and styling, among other aspects — have not received attention, instead representing an unfortunate gap in the literature about EI determinants. A related research question is whether the design capabilities that enable the development of environmental technologies themselves have an environmental nature and whether the complementarity between technology and design extends to their environmental content. Eco-design studies might make it appear that this research question has already been addressed, or is even tautological, but this is not actually so. Eco-design has been shown to work, as demonstrated by a number of case studies that have ascertained that at the end of the relevant project (i.e. ex-post), eco-design practices can be successful and actually manage to achieve more environmentally sustainable products. However, this evidence is still scant and prevents us from knowing whether a superior capacity to introduce green design can generally be expected (i.e. ex-ante) to provide firms with a premium for developing new environmental technologies, thus justifying the managerial and policy support of its development.

Recent research has suggested that EI would rely on 'distinctive sustainability-oriented capabilities' and has consistently found that 'green R&D' favours these more than general (i.e. non-green) R&D (Demirel and Kesidou, 2019). Still, in light of the technical/managerial complexity that eco-design studies have shown in their application, we do not know whether green design capabilities pay off more than standard design in spurring firms to advance environmental technologies. In brief, the plausible gain of a 'green-matching' between design and technology still remains an open question.

The second gap this paper aims to fill is empirical. Applied research on the relationship between (green) design and green technologies has been scanty so far, above all due to problems in collecting comparable data for large samples of firms. Dedicated surveys have recently been drafted and administered to firms for this scope (see, for example, the 2014 and 2015 releases of the European Innobarometer), and important results have been obtained by running econometric analyses on the these datasets (e.g. Ghisetti and Montresor, 2019; Montresor and Vezzani, 2020). However, two issues remain open also in this kind of analysis. On the one hand, in survey-based studies design and eco-design are generally captured by asking the interviewed firms about their investments in design and about the centrality of design in their business model (Ghisetti and Montresor, 2019). In brief, (green) design is defined following a 'subject-based' approach and focusing on the inputs of the relative capabilities, with all the biases these methodological choices entail (Smith, 2014). On the other hand, while evidence of a significant correlation between firms' design investment/engagement and their capacity to introduce new sustainable technologies has emerged along this survey-based stream of research, its reliability is somehow limited. In particular, as with respect to 'standard' innovations (Filippetti, 2011; Montresor and Vezzani, 2020), cross-sectional survey data do not guarantee that the detected relationship is actually a causal one.

The present paper aims to fill this second research gap by proxying firms' design capabilities with an object-based approach that uses the number of design patents at the United States Patent and Trademark Office (USPTO). Design data are drawn from the EC-JRC/OECD COR&DIP© database, covering the IP (intellectual property) bundle of the top corporate R&D investors worldwide. This is an interesting sample of firms, whose development of green technologies can be captured by looking at the patents they have filed that have a green characterisation (Hernández Guevara et al., 2019), following the Environmental Technology Classification provided by the OECD (Haščič and Migotto, 2015). In the absence of similar classifications for other IPs and in order to address the role of green design, we propose an original text-based analysis of designs, through which their environmental nature can be identified in a way that shows encouraging traces of both internal and external validity. These green design (and trademark) data are not affected by the respondent-bias of subject-based data. Furthermore, differently from previous cross-sectional (survey-based) studies, we rely on a dataset that allows us to test the relationships at stake using different regression models and to get closer to an actual causal nature for these.

The rest of the paper is structured as follows. Section 2 positions our paper in the extant literature and illustrates our research questions. Section 3 presents the dataset, our green-design measurement, some descriptive statistics, and our econometric strategy. Section 4 illustrates the main results, and Section 5 offers some concluding remarks.

2. Background literature and research questions

The role of design in driving environmental sustainability has long been translated into the concept of eco-design, mainly meant as the integration of an environmental dimension (e.g. product duration, resource efficiency, waste reduction, and the like) into new product development (Karlsson and Luttropp, 2006, Braungart et al., 2007). Most of the existing research on the topic is either based on case studies (e.g. Cerdan et al., 2009) or on limited samples of companies (e.g. Santolaria et al., 2011), making it difficult to generalize the obtained results for the sake of policy implications.

More systematic evidence on the topic has been provided by recent studies about EI. Following the so-called 'regulatory-technology push/demand-pull approach' (Horbach et al., 2012), the policy enforcement of eco-design has been claimed to represent a core driver of EI due to their structural sensitivity to environmental regulations (like the recent EU environmental directives on eco-labelling and energy-labelling). Following the same theoretical framework, EI have also been enabled by the investments and strategies that firms implement in their design activities, assuming that these can also include specific eco-design practices. For example, Ghisetti and Montresor (2019) find a positive correlation between a firm's propensity to EI and the role (centrality) design is given within the firm.

While referring to firms' decisions to put their design activities at the service of EI, previous studies do not directly focus on design capabilities and on the role these capabilities could have in spurring the capacity of developing new green technologies. Given the positive relationship between design and innovation, ascertained by innovation studies in generic terms (see Montresor and Vezzani, 2020, for a review and a recent application), this is quite unfortunate. Indeed, the capabilities that firms develop and/or acquire to introduce and implement novel design attributes — pertaining to product ergonomics, form, aesthetics and styling, among others — are highly complementary to the wider set of capabilities through which they become capable of developing new technologies. The relevance of such complementarity has been argued by the most recent theoretical accounts of the innovation process, looking at it as a complex 'chain' (i.e. system) of activities and relationships (Klein and Rosenberg, 1986). On the one hand, design capabilities are crucially interlinked with those of R&D and enrich rough blueprints and prototypes along an extra dimension (i.e. design), which contributes to making them patentable inventions. On the other hand, design is itself a source of knowledge and capabilities from which inventions can germinate, especially through learning-by-interaction with suppliers and customers.

In principle, the complementarity between design capabilities and the inventive capacity of a firm could be claimed to hold across different technologies. In other words, we should expect that this complementarity is relevant also in developing technologies with a favourable environmental impact (e.g. pollution abatement technologies, for waste management, or environmental monitoring). Accordingly, design could be expected to affect firms' green inventions also beyond the regulation-mediated mechanisms identified by the 'regulatory-technology push/demand-pull approach' (Horbach et al., 2012), that is, through a capability kind of complementarity, which the extant research has unfortunately neglected so far.

In addressing this research question, however, the specificity of green technologies and EI needs careful consideration. As Demirel and Kesidou (2019) have recently argued, EI appears to require capabilities that are inherently different from those at the base of standard innovations. To face the regulatory, technological, and market challenges that EI pose, firms would need to develop what they call 'distinctive sustainability-oriented capabilities'. In brief, rather than invariantly applying their standard innovative capabilities to the introduction of green technologies, firms are expected to renew and align them with the manifold idiosyncrasies of this technological domain. Consistent with this argument, the authors find that the probability to eco-innovate increases when firms invest in green rather than generic R&D and when they develop capabilities of 'green marketing' rather than general market sensing.

Extending this line of argument, as our first research question we investigate whether a firm's capacity to develop new green technologies is more intensively affected by green than by 'neutral' or non-green design capabilities. In brief, we wonder whether a 'green matching' between new designs and technologies could be beneficial for a firm's inventive capacity in the environmental domain.

As in the case of green R&D, green design is meant to embrace all of those design practices that firms carry out to make the functionality and/or appearance of their products/processes sensitive to their environmental impact. This definition of green design extends and specifies that provided by Tseng et al. (2013) in their introduction to a special issue of the *Journal of Cleaner Production* on the topic. According to them, green design mainly consists of the application of '*cleaner production principles of preventive strategy and source-oriented approaches, [including] toxics use reduction, enhanced durability, product/service combinations, updatability via software upgrades, [and] manufacturability [...] lead[ing] to a more ecologically sound and to lower fossil carbon footprints products and services*' (p. 2). These green design practices could actually include those the focal literature considers as eco-design in new product development (see above). However, our meaning of green design is wider than eco-design as such as it also includes all cases of ‘greening’ design that firms can implement without an explicit or even conscious application of an already codified and labelled eco-design practice (like ‘design for remanufacturing’ or ‘design for recycling’). In other words, the sole willingness and/or capacity to use and/or combine green-related elements in developing new design elements can be taken as a proxy of this wider notion of green design. In this last respect, our definition of green design is wider than that of eco-design at the ‘extensive margin’ as it encompasses a wider set of activities. However, with respect to eco-design, our green design is more selective at the ‘intensive margin’, that is, in the identification of the relevant activities as, unlike standard eco-design, it requires these activities to be novel. Indeed, the green design that we consider actually refers to a firm’s capacity to create ‘novel’ plans and/or drawing procedures of an ‘individual’ (green) character, for which firms find it convenient to ask for — and manage to obtain — intellectual property protection (Filitz et al., 2015). In brief, our green design is an innovative way of accounting for the environmental content of design, which goes beyond the simple application of already existing eco-design practices.

Two issues regarding this green design conceptualisation need to be clarified. First of all, the definition provided above reveals that green design involves an extra set of capabilities for introducing and/or implementing novel design attributes in general. These are extra competencies of environmental and sustainability principles that, if present, firms can integrate with generic design capabilities in order to make their development of green technologies more effective. In other words, while design as such could provide firms with a ‘first-order’ leverage to increase their inventive capacity across the board, and thus in the green domain too, green design can be expected to be a more powerful ‘second-order’ leverage in the same respect. In brief, the degree of complementarity between green-tech development and green design is expectedly higher than that between the former and simple design capabilities.

The second issue we need to clarify is that the reference to intellectual property protection in our definition of green designs (Filitz et al., 2015) is intended to capture an actual capability the firm has in green design activities. In other words, design property rights go beyond the capability ‘potential’ that design investments and/or design engagement in the business model could only reveal. While useful in this last respect, when a firms’ development of green technologies is captured through its green patents — as in our empirical application — using design patents and searching for their relationship with the former could confound our focal capability-based relationship with a simple IP bundling strategy of the firm. This is an important point that the empirical strategy should allow us to consider, in such a way that patents and designs do not simply represent the two layers of the same green invention. As we will see in what follows, the way we look at the relationship between green design and green patents is not capable of fully netting out cases of green inventions for which green design augmented intellectual protection has been strategically looked for by the focal firm. While this is a limitation of our analysis, the empirical strategy that we follow refers to a dataset that accounts for a wider set of green patent/green design combinations than these strategic ones, if only because tracing the application of a design to a new product for which the company has applied for a patent is technically almost impossible. Furthermore, by making design exogenous, with the same strategy we are able to go beyond the strategic co-occurrence of green design and green invention protection and look at the role that the capacity for green design (protection) has in driving the capacity for green invention (protection).

Before moving to the empirical application, we should consider that several contextual factors, both within and outside the firm (e.g. its industry), could affect the relationship between (green) design and green technologies and act as moderators of the impact the former can be expected to have on the latter. Among these factors, a firm's endowment of intangibles other than design appears to be the most relevant. As previous studies have shown (e.g. Montresor and Vezzani, 2016), a firm's capacity to innovate depends on a heterogeneous set of intangible assets. Given their higher complexity (Barbieri et al., 2020), this is possibly even more the case for new green technologies, which arguably require a wide set of firm capabilities that complement each other. Among the different intangibles, R&D and its notable 'two faces' (Cohen and Levinthal, 1989) can be expected to be crucial for the relationship between green technology and design. On the one hand, R&D investments — with the first face addressed by Demirel and Kesidou (2019) — could possibly be less directly functional than green R&D for the introduction of green technologies. On the other hand, however, the second face of R&D has been crucial in building up the 'absorptive capacity' that an effective use of green design also requires (Ghisetti et al., 2015). By augmenting their R&D expenditure, firms could actually be able to absorb external knowledge and develop capabilities, both internally and across their boundaries, which could allow them to better grasp the way green design can be used for the sake of EI.

Our second research question revolves around the complementarity between R&D and green design in favouring the development of new green technologies. On the basis of the previous arguments, our expected answer is that the R&D expenditure of firms can increase the green-tech premium firms can get from their green design. In analytical terms, we expect that R&D positively moderates the effect that green design exerts on the development of green technologies.

3. Empirical analysis

3.1 Data

Our empirical analysis is based on the COR&DIP© database, jointly developed by the JRC of the European Commission and the OECD.[2] This dataset covers the IP bundle of about 2000 top corporate R&D investors worldwide across different industries (see Table A1 in the Appendix). In so doing, it provides us with useful data about patents and design patents (and trademarks) with which to investigate our focal relationship between invention and design capabilities. In order to attenuate the impact of possible changes in the corporate structure of the sample companies, data refer to the 8-year period of 2007–2014. This is not a very long temporal window, but it represents an important step ahead with respect to previous cross-sectional analyses. Furthermore, the dataset also contains information on other economic variables of the firms in the sample (such as R&D expenditure, employment, sales, and capital expenditure), which can be fruitfully used in econometric analysis.

As the latest release of the COR&DIP© database (v.2017) was not sufficient in providing the full range information needed for our analysis, starting from the original raw matching files, we extended the data coverage by retrieving full IP information on top R&D investors from the United States Patent and Trademark Office (USPTO).[3] More precisely, we searched the IP documents for the entire corporate structure of the focal firms (about 600,000 subsidiaries) and then aggregated them at the headquarter level.[4] This led us to a sample of 16,000 observations, which fell to 12,869 due to some missing observations in our main variables (see below).

As far as patent data are concerned, in spite of remarkable limitations, patents represent a widely used proxy for a firm’s capacity to develop new technologies (Nagaoka et al., 2010). Due to the long granting lag, causing truncation in patent counting for the most recent years, and considering that the rate of rejection at the USPTO is quite low, we decided to use patent applications instead of granted patents over our reference period (2007–2014). Following previous research on the top R&D investors in question

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[2] More information about the data are available at: http://www.oecd.org/sti/inno/intellectual-property-statistics-and-analysis.htm.

[3] In particular, we removed the restriction imposed by the IP5 methodology that is used to collect patent information for the EC-JRC/OECD COR&DIP© database (see Dernis et al., 2015).

[4] In a first stage, IP documents may be assigned to multiple entries, which normally belong to the same mother company, due to the similarity of their names (e.g. different subsidiaries of the same company in one country). The aggregation procedure avoids issues related to double counting. However, in the relatively few cases in which an IP belongs to different companies (through their subsidiaries or mother companies), due to the difficulties in dealing with different specific cases we decided to assign the full IP to both companies instead of counting it fractionally. Similarly, an IP can be classified either as environmental or not, but not as partially environmental (in cases of patent documents with both an IPC code belonging to the OECD classification and one not belonging to it).

(Hernandez Guevara et al., 2019), environmental technologies are captured by looking at 'green patents', whose ICP codes fall in the environmental domains identified by the OECD Environmental Technology classification (Haščič and Migotto, 2015).[5]

As anticipated in Section 2, design capabilities are proxied by looking at the design patents of top R&D investors at the USPTO. In other words, we look at a company's capacity to creating 'novel' distinctive plans and/or drawing procedures of an 'individual' (green) character, of which they find it convenient to ask for intellectual property protection (Filitz et al., 2015). Unlike for patents, looking for *green* design patents is quite a difficult task. Their existing classification in terms of product categories to which they are intended to be applied — the Locarno classification — does not follow a technical (or use) logic, as in the case of ICP for patents, and is thus scarcely informative of their actual green content.[6] Such content is rather reflected by design descriptions and claims and could be more accurately captured through a textual analysis. In performing this textual analysis, it should be considered that design texts are relatively concise and much shorter than other science-technology information (STI) (e.g. patents or scientific papers). Furthermore, their syntax is generally too bare to search for descriptions of articulated environmental design claims of the kind we can find in green patents (see https://www3.wipo.int/designdb/en/index.jsp). Secondly, the greenness of the text we are searching for should refer to product- and design-related aspects rather than to technologies and/or technological processes, and this is difficult to impose in a fully automated text-search process. These difficulties have induced us to follow a very time-consuming 'semi-automated' procedure of text analysis, which we have carried out under the supervision of patent officers specialised in designs/trademarks and IP experts. To start with, we used as our initial dictionary the OECD Environmental Technology classification (see Haščič and Migotto, 2015) and we extracted from its textual description of green technologies all of the (single or at most composite) words that can be taken to have environmental relevance and that can possibly be found in a design claim/description.[7] We then used these words to start searching for green designs in the USPTO design database, for our sample of companies, by flagging design patents that contain at least one of the selected keywords. Through a re-iterated trial-and-error process, during this search we progressively refined the list of keywords in two respects. Firstly, we excluded the initial green keywords that apparently did not refer to design at all, providing no design records mainly because of

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[5] IPC stands for International Patent Classification, which is used to classify patents according to their technical content.

[6] For a complete list of product classes and subclasses specified in the Locarno classification, see http://www.wipo.int/classifications/nivilo/locarno.htm.

[7] In determining this relevance, in addition to 'typically' environmental words (such as, for example, 'waste' or 'pollution'), we have also considered words that refer to objects, whose design development is, according to the consulted IP experts, nowadays universally intended to improve the relative environmental efficiency of products (as in the case of 'accumulator' or 'fan-blade').

their being related to technologies and technological processes rather than to products and product functions. Secondly, we identified a list of keywords that were necessary to better specify the greenness of some of the initial ones and built up a series of co-occurrent strings that we also used in the search,[8] along with the possible combination of different green keywords (see the co-occurring cases in Table 1). As the result of this process, we obtained the list of keywords in Table 1. A similar rationale was followed to identify ‘green’ trademarks, which we will discuss in the next sections.[9]

[TABLE 1 AND TABLE 2 HERE]

As an illustrative example of the (internal) validity of the keywords that we identified, Table 2 (left column) shows some of the green design patents that we found for three companies in three different industries: Apple Inc., Denso, and Mitsubishi Electric. With respect to Apple, the identified green designs (whose claims and descriptions can be found using the reported publication number) refer to design features of laptops and their power-system components (identified by the keywords: ‘power adapter’, ‘battery’, and ‘thermal device’), whose environmental impact in terms of heat, energy, and waste appears evident. Quite interestingly, these green designs are associated with a set of green inventions by Apple (Table 2, right column) — identified by the IPCs of their patents (e.g., in methods and apparatuses for dynamic power control) — through which laptop performance has been improved in terms of energy efficiency. This is a first bit of evidence for our ‘green-matching’ argument, which is also illustrated by the other two examples. In the case of Denso, a global manufacturer of automotive parts, the green design that we found refers to the design of a component (identified with the keyword ‘electric vehicle charger’) with an evident impact in terms of energy saving, which is again associated with a related green invention in the discovery of a more efficient power supply system. A similar matching can be found with respect to Mitsubishi Electric, for which the new green design of a ‘charger for electric vehicles’ interestingly maps onto a new green technology regarding control devices for an alternating-current electric motor. Of course, these are only simple associations; however, they are encouraging in terms of the systematic relationship we are looking for in our empirical application.

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[8] For example, as all the new design registrations for tires are aimed at achieving material efficiency, with the exception of those related to specific weather conditions or uses, we used in the search for green designs the co-occurrence of the presence of the word ‘tire’ and the absence of the words ‘snow’, ‘rain’, ‘race’, ‘slick’, ‘soft’, and ‘weather’.

[9] In this case as well, existing classification schemes such as the Nice Classification (https://www.wipo.int/classifications/nice/nclpub/en/fr/) are not suitable for our research question.

As far as the external validity of the identified green designs is concerned, as well as that of the related results, our focus on top R&D investors apparently makes these problematic. This is for sure an ad-hoc sample, made up of mainly large conglomerated and multinational firms. However, these are companies on whose inventive efforts the green technologies adopted by many countries largely depend, as more than half of the patents related to green technologies at the USPTO and the European Patent Office (EPO) are filed by them (Hernández Guevara et al., 2019). Moreover, these are usually large multinational corporations (MNCs) simultaneously exposed to different cross-country environmental regulations and to global and local environmental pressures (Marin and Zanfei, 2019). This makes their engagement in green design and inventions even more pressing than for other companies.

Besides these reasonable conjectures about the larger exposure of our sample firms to green design and technologies with respect to the universe of firms, and with the identification of green design being an original contribution of this work, we lack primary external data to compare the green design outcomes of top R&D investors with those of other firms. We are thus unable to directly assess the external validity of our green-design classification. Still, as indirect proof, we can relate what emerges in terms of green design from applying our classification to top R&D investors with what emerges from other evidence on the topic with respect to wider contexts. An interesting reference in this last respect is represented by the 'product groups' that the European Commission identified when designing the working plan for the EU Eco-Design Directive (European Commission, 2008), i.e. the product groups in which it is most likely to expect eco-design activities (see Table A2 in the Appendix). Looking at the internal documents that accompany each of the 9 eco-design product groups (available from the DG GROW website),[10] it appears evident that their identification has been guided by the EC analysis and consultation with experts and the association representatives of various industries within European countries, in principle comprising firms of any size and market. Accordingly, this can be considered a reliable external benchmark for our green-design classification.

In order to relate our results to this benchmark, in Figure 1 we report the distribution of green design patents we detected for our sample across Locarno classes (in green) and the share of design patents classified as green in each Locarno class (in yellow).

[FIGURE 1 HERE]

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[10] https://ec.europa.eu/growth/industry/sustainability/ecodesign/product-groups_en.

Quite interestingly, more than half of the green designs in our sample are associated with products related to ‘Equipment for production, distribution or transformation of electricity’, to which the EC eco-design product groups Lot2 and (at least indirectly) Lot7 and Lot8 are related, and to ‘Means of transport or hoisting’, related to Lot5. The remaining most-populated Locarno classes in our sample are ‘Lighting apparatus’, ‘Recording, telecommunication or data processing equipment’, and ‘Fluid distribution equipment, sanitary, heating, ventilation and air-conditioning equipment, solid fuel’, which refer to product groups Lot9, Lot3, and Lot6.[11] ‘Equipment for production, distribution or transformation of electricity’, ‘Means of transport or hoisting’, ‘Lighting apparatus’, and ‘Recording, telecommunication or data processing equipment’ are also the Locarno classes with the highest shares of green designs in our sample, with an interesting mapping onto the product classes that the EC has identified as most involved in eco-design activities.

While certainly indirect, the degree of mapping we have found between our original green design evidence and the eco-design product classes in policy documents is encouraging in terms of the external validity of our classification. Indeed, it remains true that our sample targets a specific kind of company, for which the resorting to design rights could be greater than for other smaller and less multinational firms. Accordingly, the external validity of our classification will have to be more directly evaluated with respect to larger samples of firms in future research.

3.2 Variables

3.2.1 Dependent variables

The focal dependent variable of our analysis is the number of patent applications made by each and every company (top R&D investors) in the environmental domains listed in the OECD Environmental Technology classification (Green patents, acronym *GREEN_PAT*) and its log-transformation (*lGREEN_PAT*), for the sake of elasticity analysis. In order to test our green-matching hypothesis, we also build up the total number of patents applied by each firm in time (*PAT*), its log-transformation (*lPAT*), and the total number of applied patents that do not belong to the green domain (*NO_GREEN_PAT*), still with its log transformation (*lNO_GREEN_PAT*).

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[11] Lots are listed in Table A2 in the Appendix

We first get rid of the excess of zeros in the count of environmental technologies by defining the following log-transformed variables: *l(GREEN_PAT + 1), l(PAT + 1),* and *l(NO_GREEN_PAT + 1).*[12] As this transformation could affect the results, we also perform our analysis on the not log-transformed variables by using count data models. Finally, in order to better handle the extreme values of the dependent variables, estimates are also performed by applying an inverse sine transformation to the count of green patents (Burbidge et al., 1988).

3.2.2. Explanatory variables

Moving to the explanatory variables, the focal ones to test the green-matching hypothesis are *DESIGN*, which counts the number of designs that each company has filed in a given year, *GREEN_DESIGN*, counting only those designs that can be claimed to have an environmental component, and *NO_GREEN_DESIGN*, as the residual component of design applications when subtracting designs with a green component. As in the case of patents, *DESIGN*, *GREEN_DESIGN,* and *NO_GREEN_DESIGN* are log-transformed in *lDESIGN*, *lGREEN_DESIGN,* and *lNO_GREEN_DESIGN* for the sake of elasticity analysis.

An important point about our focal *DESIGN* regressors concerns their possible endogeneity. First of all, we have to account for that arising from reverse causality, which could in principle go in both directions, that is, it could be that firms patenting more get higher design capabilities. As will be discussed and motivated in the following section, two instruments have been adopted to mitigate this problem: the number of trademarks registered by each and every firm (*TM*) and the share of the whole sample's trademarks that are registered in the industry where the focal firm operates (*TM_sector*).

3.2.3 Controls

In order to reduce unobserved heterogeneity, we insert a set of control variables for each of the three dimensions suggested by the existing literature on the drivers of green technology at the firm level (e.g. Horbach et al., 2012). First, in order to account for environmental regulation and in the absence of micro-data, we use an aggregated measure and consider the (3-year moving average of the) OECD Environmental Policy Stringency indicator for the countries where the scoreboard companies in our

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[12] Given that by adding 1 to their distribution—in order to avoid the loss of their zero values—we have changed the original distribution of our dependent variables and, as we will see, of our focal design regressor as well, the relative elasticity cannot be read with precision. However, since the transformation in question occurred on both sides of the equation, we are confident that it does not substantially alter the estimated effect.

sample are headquartered (*lENV_REG*). While invariant with respect to the companies headquartered in the same country, this indicator accounts for multiple dimensions of the environmental policy and includes most of the existing policy instruments (Botta and Kozluk, 2014; Albrizio et al., 2017). Second, demand conditions are approximated by the amount of company sales at constant prices, once again log-transformed (*lDEMAND*); a variable that, to avoid collinearity problems, we also mean to control for the (economic) size of the focal firms.[13] Third, we account for the innovative capabilities of firms by referring to the amount of their R&D investments at constant prices and by log-transforming them (*lRD*).

R&D investments are also used to test our second research hypothesis regarding the moderating role that R&D is expected to exert on the relationship between green design and green technologies. In considering this interaction, the possible overlap between design and R&D activities at the company level should be accounted for as it could affect our results. In large companies like those in our sample, some design activities are often implemented within overall functions of Research and Development and Design (RD&D), whose investments might thus also include design expenditures. However, as Moultrie and Livesey (2014) have illustrated in a recent study on the topic, '[d]esign also spans organizational boundaries, and will find different (or possibly multiple) functional homes even within a single sector' (pp. 572–573). In particular, while a 'technical kind of design' can actually find a home in R&D departments, there is an important part of 'user-focused design' that normally falls outside of them (on this distinction, see Tether, 2006). For this reason, 'product design does not always depend on R&D and R&D does not always lead to new product [designs]' (ibid., p. 571). On this basis, treating design and R&D as separate variables should not affect the reading of our results regarding their interaction, especially considering that the former is measured in output terms and the latter in inputs terns.

In addition to the previous set of controls, firm-specific individual characteristics are controlled for by using standard errors clustered at the firm level as well as by performing a panel analysis with fixed and between effects (see the next section). Finally, eleven sectoral dummies, following the grouping reported in Table A1 in the Appendix, are included in all specifications (and not reported in the tables), as well as yearly time dummies. Given that the variable relative to environmental policy stringency is only available at the country level, country dummies are not included as they would be collinear.

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[13] As a matter of fact, given that the correlation with the number employees of the firm is very high (0.91) and sales are highly indicative of the size of the firm, we chose not to include additional measures of size among the covariates. The main results (available upon request) are robust to the inclusion of the number of employees in the firm. The only exception to these robust results happens with respect to the variable *lDEMAND*, which loses its significance once including the size of the firm, due to its collinearity with that measure. Results (available upon request) are also robust to the exclusion of R&D.

Table 3 presents the main variables and reports their main descriptive statistics. Table 4 reports the pairwise correlation among those variables. Figure 2 shows the largely skewed distribution of the IP variables, which we will have to consider in our econometric estimations.

[TABLE 3 and 4 HERE; Figure 2 HERE]

We must note that the intense patenting and design activity of the top R&D investors is only partly directed toward a greener kind of technological change. Indeed, sample firms are split in this respect, with 57% and 22% of them having filed and registered at least one green patent and one green design, respectively (Table A1 in Appendix). Further insights emerge when cross-tabulating the shares of top R&D investors that resort to different kinds of IP. Of the firms in the sample, 38% have applied for both green patents and design patent rights in general, while only 19% of the firms in the sample have applied for both a dedicated green design and a green patent. Finally, almost all firms (98%) owning a design right have also registered a trademark; only 1% of the firms that have a *GREEN_DESIGN* have no *GREEN_TM*, while 21% of the firms in the sample have both a *GREEN_TM* and *GREEN_DESIGN*.

3.3 Econometric strategy

The empirical strategy that we follow is composed of a set of intertwined methods.

To start with, in order to see whether the determinants of environmental and non-environmental technologies are marked by significant differences, particularly with respect to the role played by design, we estimate seemingly unrelated regressions (SURE), with *lGREEN_PAT* and *lNO_GREEN_PAT* as dependent variables. The Breush–Pagan test of independence of the error terms shows that the two models have correlated residuals, thus supporting this choice.

Once it is established whether environmental and non-environmental technologies differ in terms of the role played by design and green design, the analysis concentrates on environmental technologies. We start by estimating a pooled OLS in which the dependent variable is *lGREEN_PAT* and in which the main explanatory variables are included one by one, starting from *DESIGN* and moving to *GREEN_DESIGN* and to the interaction between *GD* and R&D *(GD*lRD)*, where *GD* is a dummy taking a value of 1 if a firm has at least 1 registered design with an environmental component in a year. This last interaction enables us to test our second research hypothesis, according to which R&D would allow firms to better translate their design activities into green technologies. Given the extremely skewed distribution of the continuous variable *GREEN_DESIGN*, with its excess of zeros (see Figure 2), the coefficient of its interaction with R&D (also continuous) could have been incorrectly interpreted. Accordingly, we decided to use *GD* instead of *GREEN_DESIGN* when evaluating the moderating effect.

In order to move closer to a causality relationship between green technologies and our design variables, the relative model is then estimated with panel analysis techniques. In particular, we run estimations using fixed-effect (FE) and between-effect (BE) panel specifications. While the former better captures time variation (differences within a firm), the latter is more suitable to deal with cross-sectional variation (differences between firms). These specifications include time fixed effects.

Finally, in trying to address the risk of reverse causality, we resort to instrumental variable regressions by searching for proper instruments to make design exogenous. In particular, we chose two instruments for *DESIGN* (and *GREEN_DESIGN*): the amount of trademarks (log-transformed) obtained by the top R&D investors of our sample (*TM*) and the share of trademarks in each and every industry (according to the 2-digit NACE rev.2 sector) in which R&D investors operate (*TM_sector*).[14]

As is usually the case, for *TM* to be a proper instrument it should be correlated with the endogenous design regressors but directly uncorrelated with the dependent variable *GREEN_PAT* (i.e. the correlation should pass only through the design–*GREEN_PAT* relationship). Indeed, this is what we argue from a conceptual and empirical point of view. Following a theoretical perspective, we first maintain that *TM* and design are expectedly correlated as they both serve to increase the distinctive capacity of the firm with respect to its products (WIPO, 2014). Still theoretically, we claim that while design is integrated in the firms' product development and contributes to their innovative and green technological solutions (Filippetti, 2011; Ghisetti and Montresor, 2019; Montresor and Vezzani, 2020), that is, to *GREEN_PAT*, this is not the case for *TM*. Indeed, unlike design, *TM* does not add intrinsic novelty to the firms' products/processes in terms of functions and/or aesthetics and does not convey new knowledge to them. The extant literature appears to provide consistent evidence in support of these two requirements for using trademarks as instruments. In particular, unlike design, which could be claimed to reflect capabilities complementary to those of patenting (see Section 2), *TM* is related to capabilities that do not directly relate to a firm's capacity to develop and invent new technologies. For example, Greenhalgh and Rogers (2012) show that firms resort to *TM* in cases (such as services) in which incremental product innovations are unsuitable for patent protection. Similarly, in a recent study by Flikkema et al. (2019), firms appear to apply for *TM* mostly in the final phases of the innovation process, namely in the marketing

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[14] Robustness checks on alternative instruments (*GREEN_TM* and *NO_GREEN_TM*) have been performed. The results are reported in the Appendix (Table A3) and discussed in Section 5.

phase, whereas patents are rather more suitable in earlier stages of product development. In the same vein, Athreye and Fassio (2019) highlight that the use of *TM* mostly characterizes innovative activities in services, which cannot be patented. Overall, these studies suggest that a distinction exists between patent-based measures, which operationalize technological assets, strategies, and capabilities (Hsu and Ziedonis, 2013), and *TM*, which instead captures reputational assets, market strategies, or downstream capabilities (Castaldi, 2018, 2019; Dosso and Vezzani, 2019). As a confirmation of this, Castaldi and Dosso (2019) argue that trademarks may help identify non-patentable innovations, such as non-technological forms of innovation or service innovations, in which *TM* is used as a substitute to patents. In the same vein, the industry share of *TM* (*TM_sector*) does not directly account for the firm's capacity to develop new green technologies but helps explain the *DESIGN* of the focal firms. An industry in which the resorting to *TM* is more diffused would probably represent an environment in which the sensibility to the symbolic and aesthetic nature of products is greater. Accordingly, in these industries firms will have a higher chance of benefiting from knowledge *spillovers* in implementing design, stemming from those paying attention to product characteristics and seeking to obtain protection for them. As we will show in the next section, these conceptual arguments are confirmed by a more dedicated empirical validation of our instruments.

Before moving to the results of the econometric analysis, we must note that the binned scatterplots among the focal variables confirm our expectations of a positive correlation between design and patents.[15]

[Figure 3 HERE]

In Figure 3, both design (left-hand side) and green design (right-hand side) appear positively correlated with both general (upper panel) and green patents (lower panel), showing some trace of the green-matching hypothesis we are looking for. However, these relationships could be spurious and require an econometric analysis in order to control for other possible determinants and identify more reliable linkages.

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[15] Binned scatterplots are a non-parametric visualization of the relationship between two variables based on a grouping of the x-axis variable into equal-sized bins, a computation of the mean within each bin (for both axes), and the creation of a scatterplot of these data points. Fit lines are also plotted. Binned scatters have been created by the command 'binscatter' in Stata (Stepner, 2014).

4. Results

4.1. Design, green design, and non-green design vs general, green, and non-green technologies

The results of the SURE estimates, reported in Table 5, show that the introduction of green and non-green technologies is correlated with a similar set of determinants.

[TABLE 5 HERE]

DESIGN is correlated with both environmental and non-environmental inventions, and the same holds true for *GREEN_DESIGN*. Quite interestingly, the inventive effect of *GREEN_DESIGN* seems to also spill over to technologies outside of the green domain. In other words, introducing novel designs with environmental functionality seems to have a sort of general purpose relevance for the R&D Scoreboard companies in question. As for the main controls, they all behave as expected. The only exception is represented by the role of sales (*DEMAND*), which seem to be clearly significant only with respect to green technologies, whereas they show a less clear-cut correlation with the remaining technologies.[16]

More interesting results are obtained when both *GREEN_DESIGN* and *NO_GREEN_DESIGN* are simultaneously included in the estimates, as in column (3). While *GREEN_DESIGN* has a larger coefficient than *NO_GREEN_DESIGN* when we consider *GREEN_PAT* as the dependent variable, the opposite holds true when the dependent variable is *NO_GREEN_PAT*. In terms of elasticity, the specification at stake with log-transformed (x+1) variables[17] reveals that a 1% increase in *GREEN_DESIGN* results in an average change of 0.39 % in *GREEN_PAT*, while the same increase in *DESIGN* results in a much smaller change (0.13%) in *GREEN_PAT*. This result further corroborates the idea that a green-matching helps the development of green technologies more than a matching with general design capabilities. Indeed, this appears as a first bit of evidence of the 'green-matching' hypothesis we are investigating, supporting the argument that environmental technologies require a 'distinctive sustainability-oriented capability' (Demirel and Kesidou, 2019) also with respect to design.

In the same set of SURE regressions, the effect of R&D on *GREEN_PAT* is smaller than that of *GREEN_DESIGN*; in contrast, the correlation between R&D and *NO_GREEN_PAT* is much larger than that associated with design. In other words, while R&D would seem to appear more effective than *DESIGN* in the development of non-environmental inventions, *GREEN_DESIGN* seems to have a

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[16] An in-depth analysis would be needed to understand whether this result, pointing to an unexpectedly negligible market role for non-green technologies, is generalizable to other firms other than large top R&D investors.

[17] We have to recall that having added 1 to both distributions of GREEN_PAT and GREEN_DESIGN to avoid the loss of their zero values, the relative elasticity cannot be read with precision.

prominent role in stimulating environmental ones. Quite interestingly, this corroborates previous evidence about the pivotal role that design plays in the introduction of green technologies with respect to other technological and non-technological intangibles (Marzucchi and Montresor, 2017; Ghisetti and Montresor, 2019). Furthermore, it suggests that the combination of these two intangibles — R&D and green design — deserves deeper scrutiny in addressing the development of green and non-green technologies. To assess this aspect, in column (4) of Table 5 we introduce the interaction term *GD*lRD*, where, as previously mentioned, *GD* dichotomizes *GREEN_DESIGN*.

As expected, substantial differences emerge between *GREEN_PAT* and *NO_GREEN_PAT* from this specification. With respect to non-environmental technologies, all of the focal variables have a positive and significant correlation, and an endowment of *GD* and R&D moves in the same direction of (general) patent applications by top R&D inventors. However, an incremental effect of green design does not emerge at higher levels of R&D. The same does not hold true for environmental technologies. When *lGREEN_PAT* is the dependent variable, *GD* alone has a significantly negative coefficient, and it is only when moderated by R&D that its coefficient turns out to be positive. For low levels of R&D investment, having or not having introduced novel green designs is not significantly correlated with (possibly does not have an effect on) the development of new environmental technologies. This evidence is confirmed by the visualization of the marginal effects of the interaction terms between *GD* and different distributional levels of *R&D* (10th, 25th, 50th, 75th, and 90th percentiles) on *lGREEN_PAT*: as reported in Figure 4, the confidence intervals of the two effects overlap up to the 25th percentile of the R&D distribution.

By contrast, when R&D investments overcome their 25th percentile, we observe a higher amount of environmental patent applications in firms with environmental designs than in other firms.

[FIGURE 4 HERE]

Green design does not seem to be rewarding *per se* in the development of new environmental technologies. Rather, it seems to pay off only when combined with R&D. In other words, firms may benefit from green economies of scope only when the amount of investment in R&D is sufficiently large. These results are consistent with the interpretation that for high enough levels of R&D investment, the marginal cost of translating innovative inputs into outputs decreases due to the exploitation of complementary efforts. In other words, it seems that the joint effort of R&D investments and design capabilities reduces the unitary costs associated with each of the two processes. The overall effect on *GREEN_PAT* is greater when the two capabilities (of designing and of investing in R&D) are combined;

conversely, for low levels of R&D there seems to be a clash between design and the invention of new green technologies. This clash, which is the main difference observed between *GREEN_PAT* and *NO_GREEN_PAT*, may be partially explained by the higher complexity of green technologies, due to their drawing on more dispersed technological fields and knowledge components (Barbieri et al., 2020). This complexity may in fact create a barrier to making design capabilities complementary to inventive capabilities or to integrating the different knowledge base that pertains to them (Grant, 1996), and this might limit the effectiveness of design only for high levels of R&D and the associated capabilities. In the absence of detectable ingredients to measure this green design complexity — similar to the role played by the number and/or distribution of IPC codes and citations (forwards/backwards) with respect to patents — this is an interpretation that further design data collection (i.e. a wider textual analysis than that carried out for *GREEN_DESIGN*) will enable us to test in future research.

4.2. Design vs green design in developing environmental technologies

In order to investigate whether green technologies actually require distinctive green design capabilities, in the rest of the analysis we test whether *DESIGN* and *GREEN_DESIGN* are differently associated with *GREEN_PAT* using the different estimation approaches discussed in Section 3. The relative results are reported in Table 6. In particular, columns (1) and (5) refer to pooled OLS models with standard errors clustered at the firm level and where *lGREEN_PAT* is estimated with respect to l*DESIGN* and l*GREEN_DESIGN*; columns (2) and (6) report the corresponding fixed-effect panel regressions; columns (3) and (7) report the results of between-effect panel regressions; and columns (4) and (8) those of the instrumental variable regressions. Specification (9) augments that in (5) by including the interaction between *GD* — whether the focal firm has registered environmental designs — and its R&D efforts, still estimated by pooled ordinary least squares with clustered standard errors.

[TABLE 6 HERE]

In all of the specifications, *DESIGN* and *GREEN_DESIGN* are significantly and positively correlated with *lGREEN_PAT*. Quite interestingly, a matching effect emerges insofar as an environmentally functional use of design is associated with the introduction of environmental technologies. While a positive correlation emerges also with respect to a more generic configuration of design, the coefficient associated with *GREEN_DESIGN* is significantly larger than that attached to *DESIGN*.

When looking at the moderating effect that R&D plays on the relationship between *GD* and *lGREEN_PAT*, our previous evidence is also confirmed. As a firm's R&D investment increases, so does its complementary effect with green design, suggesting that spillover effects could increase its efficiency in obtaining green innovative outputs. When R&D is low, instead, having or not having developed and exploited green design capabilities does not seem to play a significant role in the development of green technologies. Again, it is only for relatively large amounts of R&D investment that green design makes a difference in improving green invention efficiency. Our previous argument about the green-design magnifying role of R&D is thus confirmed.

As mentioned in the methodological section, the previous results may be biased by the potential endogeneity of the design regressors and this could prevent us from reading them in terms of (at least logical) causality. This is confirmed by the Durbin–Wu–Hausman test, which rejects the null hypothesis that *DESIGN* and *GREEN _DESIGN* are exogenous. We try to address this issue by adopting an instrumental variable approach.[18] In particular, we choose two instruments for *DESIGN* (and *GREEN_DESIGN*): the amount of trademarks (log-transformed) obtained by the top R&D investors of our sample (*TM*) and the share of trademarks in each industry (according to the 2-digit NACE rev.2 sector). Our previous arguments about the choice of *TM* as an instrument for design-related variables in their relationship with green patents are supported by our data. The Stock and Yogo (2005) test for weak instruments displays an F statistic p-value lower than the 5% threshold, thus failing to accept the null hypothesis of weak instruments. In order to test for the validity of the instruments, we also performed the Hansen–Sargan test of overidentifying restrictions and, as the p-value is above the 0.05 threshold, we do not reject the null hypothesis and conclude that the overidentifying restrictions are valid.

Having been reassured about the reliability of our IV strategy, the results of the relative estimates, reported in columns (4) and (8) of Table 6, can thus be interpreted as causal relationships (or at least are not affected by a simultaneity bias). Both *DESIGN* and *GREEN_DESIGN* can be deemed as significant drivers of *GREEN_PAT*. Developing design-related capabilities and introducing novel designs across the board increases the capacity of top R&D investors to introduce environmental technologies. This confirms, from an object-output perspective, what previous studies have found by using a subject-input perspective (Montresor and Vezzani, 2020). Once more, green design helps firms develop green technologies to a larger extent than a general kind of design, supporting our green-matching hypothesis and the underlying interpretation about the need for ‘distinctive sustainability capabilities’ for eco-innovating (Demirel and Kesidou, 2019). The difference in the *GREEN_PAT* elasticity between *GREEN_DESIGN* and *DESIGN* also still appears remarkable, the former being at least double of the latter across all of the specifications reported in Table 6. The ‘green-matching’ we have focused on,

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[18] Because of the poor results obtained with the fixed-effects specification, in which most of the coefficients are not significant, we prefer to avoid the use of GMM estimators.

between design and inventive capabilities, actually helps companies introduce novel environmental technologies.

5. Robustness checks

In order to check whether the non-linear transformation of the data introduced by the use of log variables determines our estimates, Table 7 reports the results of the analysis using a count dependent variable (*GREEN_PAT*, defined as in Section 3) estimated by maximum likelihood.

[TABLE 7 HERE]

Given the dispersed distribution of *GREEN_PAT*, we first estimate binomial models and report the results in columns (1), (4), and (7). We then account for the possibility that the process generating the zeros in *GREEN_PAT* is different from that generating positive values by using a zero-inflated negative binomial. This is based on two estimations: i) a probit model, which evaluates the probability of having or not having a positive realization of the outcome (depending on the same set of variables that drive the positive counts), and ii) a truncated negative binomial, which estimates the effect of the explanatory variables on the positive values of *GREEN_PAT*. Columns (2) and (5) of Table 7 report the results of these models. Finally, we include individual fixed effects in the model and estimate it by accounting for the variation generated by individual characteristics via fixed-effects overdispersion models.[19] Results are reported in columns (3) and (6). As far as the explanatory variables are concerned, for the sake of the present robustness check we avoid the log transformation of the count variables of interest that are also skewed towards zero, i.e. *DESIGN* and *GREEN_DESIGN*.[20]

The set of results obtained with the previous checks largely confirms the evidence we have obtained so far. The result that both *DESIGN* and *GREEN DESIGN* stimulate inventions in environmental technologies appears robust, and the fact that the latter also shows significantly larger coefficients than the former is also robust.

As for the interaction between R&D and *GD*, following the drawbacks of interpreting interaction effects in non-linear models—as discussed in Ai and Norton (2003) and Zelner (2009)—we choose to provide

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[19] Using the Stata command xtnbreg with the FE option.

[20] It is important to note that while 50% of our sample firms did not register design rights in the period of 2007–2014, we cannot distinguish the firms that did not file designs from those that completely lack these types of activities (Filitz et al., 2015). In order to deal with this issue, as suggested by an anonymous reviewer, we have restricted the analysis to the firms that have at least one patent design over the years considered. Results, available upon request, are also robust to this choice and confirm the main findings of this work.

a visualization of its magnitude for different percentiles (10th, 25th, mean, 75th, and 90th) of the R&D distribution in Figure 5.

[FIGURE 5 HERE]

The previous results are once more confirmed: for small amounts of R&D investment, having *GREEN_DESIGN* capabilities does not seem to matter more than more general design capabilities for *GREEN_PAT*. However, when the amount of R&D expenditure increases, we observe i) an increasing capability of firms to translate their green design capabilities into environmental inventions and ii) an increasing difference between the effects of green and standard designs, with the former displaying a larger return than the latter. Having developed new green design components increases the likelihood of developing and patenting environmental technologies once combined with high enough levels of R&D.

In addition to resorting to count models, other robustness checks have been carried out that also confirm the main results of our analysis. Firstly, we tested for alternative instruments to *TM*. We re-run our estimates by using as an instrument for *DESIGN* and *GREEN_DESIGN* the firms' trademarks in domains other than environmental ones, that is, *NO_GREEN_TM*. Drawing on our matching hypothesis, this last variable can be claimed to be conceptually more distant from our focal dependent variable, *GREEN_PAT*. The results, reported in columns (1) and (2) of Table A3, are robust, and coefficients remain comparable to those obtained in the main text. Secondly, we used the total number of *green* trademarks at the firm and at the industry level, instead of the general *TM* discussed above, as instruments in the IV strategy. These results, reported in column (3) of Table A3, are robust to this control. We chose to leave these two controls in the Appendix because in both cases (*NO_GREEN_TM* or *GREEN_TM*), we do not have any strong argument (neither in theory, nor in empirical terms) indicating that they would be a better instrument for *DESIGN* and *GREEN_DESIGN* than *TM* as such. Furthermore, we recognize that our proposed selection of keywords might be more appropriate for patents and design patents than it is for trademarks. Indeed, our classification strategy may flag as 'green' trademarks that are related to products and services that do not necessarily incorporate new technological or functional content; in other words, by classifying as 'green' entire classes of products and services, we may somehow overestimate the share of green *TM*. Thirdly, pooled OLS and panel FE were re-run by including the residual component of *DESIGN*, once having subtracted *GREEN_DESIGN* from it (*NO_GREEN_DESIGN*), jointly with *GREEN_DESIGN* (columns 4 and 5 of Table A3 in the Appendix), as this would in principle strengthen the argument of green matching. As expected, the coefficient of *GREEN_DESIGN* is higher than that of *NO_GREEN_DESIGN*.[21]

Finally, results obtained with the log(x+1) transformation are confirmed when using the inverse sine transformation of the dependent variable, *GREEN_PAT*, according to the following formula (Burbidge et al., 1988):

$$GREEN\_PAT = log\ [GREEN_{PAT_{i,t}} + (GREEN_{PAT_{i,t}} + 1)^{\frac{1}{2}}]\ .$$

As Table A4 in the Appendix reveals, this robustness check also confirms our results.

6. Conclusions

Motivated by the increasing recognition of the importance of design at the policy level for the sake of environmental sustainability and economic circularity (EC, 2015; EEB, 2015), in this paper we have investigated whether a green-oriented capacity for design can increase firms' capacity to develop new green technologies. Albeit there exists theoretical motivations supporting the idea that a 'green-matching' between design and technological development can increase the impact of the former on the latter, the role of green design in green inventions has been largely neglected so far. Policy recommendations have mainly been inspired by successful but non-systematic stories of eco-design business and engineering practices. The extent to which other intangibles can help firms turning their green designs into green technologies has also been neglected so far and led us to investigate whether R&D expenditures can amplify the 'green matching' effect of design. We deem this an important element for more effective tailoring of the policy support of eco-innovation at the firm level.

In order to fill these gaps, in this paper we have conducted an original analysis of the role that standard and green design can have in stimulating firms' green inventions. Referring to the world's top R&D investors and to the EC-JRC/OECD COR&DIP© database regarding their IPs, we have carried out this analysis with an object-based, rather than subject-based (i.e. survey-based), approach to design. This has been done by building up an indicator of firms' capabilities to develop novel designs in the green domain and by crossing this with their patenting capabilities in the same domain. We have also addressed the

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[21] It should be stressed that given the lack of adequate instruments, we could not jointly treat the endogeneity of these two variables. Consequently, since for this reason results are not fully trustable, we leave this analysis as a robustness control.

endogeneity of our focal regressors and tried to identify what could be deemed an actual causal relationship between (green) design and environmental technologies.

Our results show that environmental technologies differ from non-environmental ones with respect to the driving role of both design and R&D. While R&D appears more effective than design in stimulating non-environmental inventions, green design has a prominent role in stimulating environmental ones. More precisely, while generic design has an effect on green technologies as well, that of green design is actually much larger. Confirming our expectations, R&D reinforces the impact of green design on green inventions only above a certain level of firm R&D expenditure. This points to the need for a minimum level of innovative competency and absorptive capacity for the green matching to work. Conversely, below such a threshold green design may even reduce green patents due to a possible clash between the management of the two intangibles in the face of the higher complexity of green technologies.

Strategic and policy implications can be drawn from our contribution. The successful implementation of green design, meant as an innovative and environmentally sustainable use of design, requires firms to organize their business models and organisational structures in such a way as to proficiently benefit from this strategy and avoid the potential clash between different internal innovative efforts. From a policy perspective, not only should firms be made aware of new opportunities to extend the environmental dimension to design — for example, through a circular-economy — but they should also be incentivized to invest and manage intangibles, such as design, possibly in a strategic way. This is reflected in an improved understanding of how to stimulate environmental technology uptake, which has shown its ‘win–win’ potential of combining economic and environmental goals, thus helping to meet the EU2030 strategy targets and the associated Sustainable Development Goals targeted at ‘Sustainable Production and Consumption’.

Of course, this analysis is not free from limitations that the nature of the available data unfortunately does not allow us to overcome. First, the results might be specific to the idiosyncratic sample of firms used, the top R&D investors, whose bundles and management of IP and intangibles might not be representative of the entire universe of firms. Still, this sample concentrates a remarkable share of world R&D expenditures, patents, and designs (see Hernández et al., 2019), indicating that the detected relationships are at least suggestive of what could be found in other contexts of analysis. Second, the textual analysis through which green design and trademarks have been identified may need further external validation and refinement. That said, we believe that our work represents a starting point for future analyses regarding green design, through which its accuracy could be further investigated.

Tables and Figures

Table 1: List of keywords used to identify green designs and trademarks

Single keyword
accumulator; aerodyn*; battery; biodiv*; biof* (e.g. biofilm, biofuel); brake; capacitor; carbon*; charg* (excluding co-occurrences with money, cash, currency, card) desalini*; dioleect*; disassemb*; dust; efficien*, engine (excluding co-occurrences with cover, search, computer, internet, and game); geotherm*; insul*; led; modular; nuclear; oled; organic; photov*; plasma; pollut*; radioact*; recover*; recycle*; refill*; remanufact*; resist*; reus*; saving, solar; standardi*; therm*; tire/tyre (excluding co-occurrences with snow, rain, race, slick, soft, and weather); waste
Co-occurrence of keywords
Air + condit* or pump* or control* Bio + reac* or dies* or etha* or gas* or plast* or degrad* Electric* + switc* or vehi* or motor* or connec* or sock* or photo* Ener* + stor* or renew* or water* or wind* or hydr* or marin* or alternate* or tidal Environmental + device or good or frield* or sustain* or managem* or econo* Fan + blade or part* Filter + air* or car or vehi* Fuel + pump* or cell Hybrid + air* or vehi* Light* + diod* (excluding co-occurrences with lcd and game) Natural + gas Power + cable or adapt* or electr* or cord* or control* or managem* Purif* + water* or air* Smart + grid Steril* + water* or air* Water + stor* or conserve* or distrib* or collect* or treat*

Note: The keyword search was performed both in the description and in the claims of the design documents and in the description of the trademark documents. * is a wildcard allowing for liberal characters. Where the wildcard is not reported, keywords have also been searched for in their plural form.

Table 2: Some examples illustrating the idea of green matching

Green Designs	Green Patents
Apple	
'Electronic device' *[laptop]* (p.nr. D0696244)	'Methods and apparatuses for dynamic power control' (p.nr. 13708070)
'Power adapter' (p.nr. D0662473)	'Bleeder circuitry for increasing leakage current during hiccup modes of power adapters' (p.nr. 13648131)
'Battery' (p.nr. D0708128)	'Battery charging system and mobile and accessory devices' (p.nr. 13573515)
'Thermal device' *[cooling system]* (p.nr. D0708592)	'Controlling a flyback converter for use with a computer system' (p.nr. 13490297)
Denso	
Electric vehicle charger (p.nr. D0719089)	Power supply system (p.nr. 13774221) *[battery-related]*
Mitsubishi Electric	
Charger for electric vehicles (p.nr. D0734249)	Control device of alternating-current electric motor (p.nr. 14785912)

Note: p.nr. stands for publication number (at the USPTO)

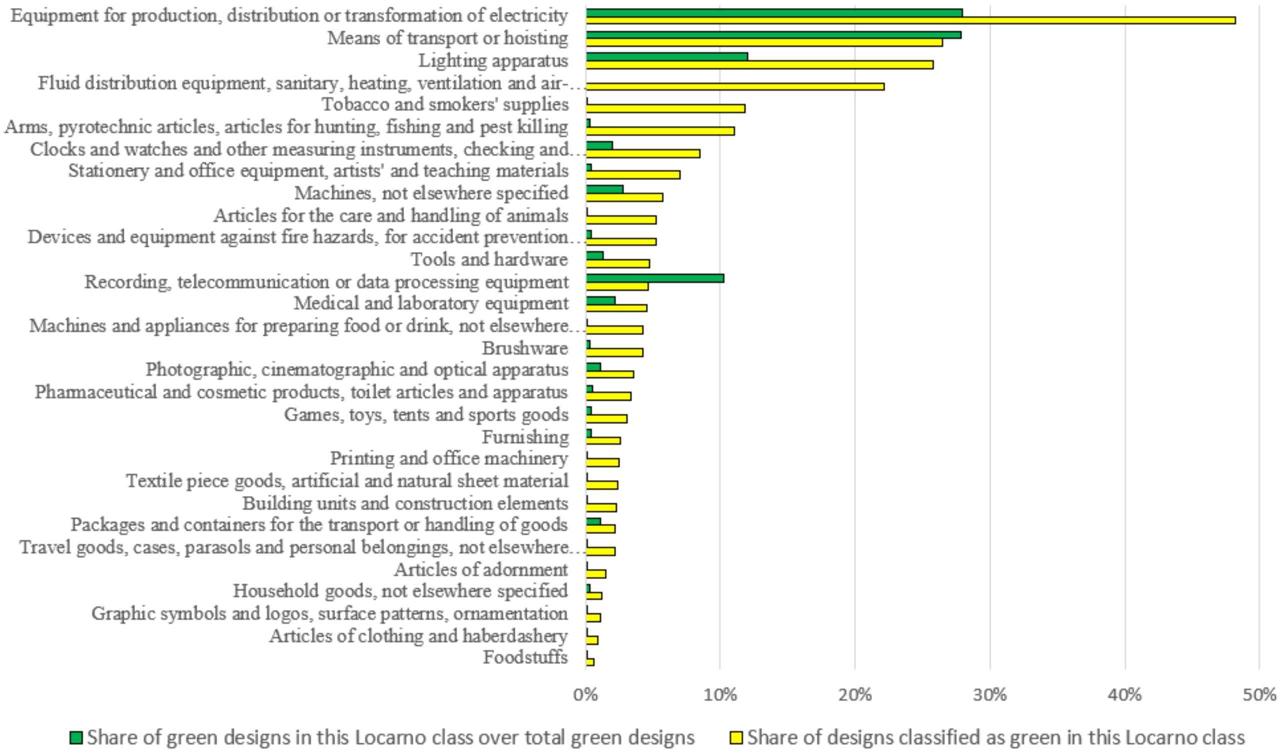
Table 3: Descriptive statistics: main variables (full sample)

VARIABLE	DESCRIPTION	N	MEAN	SD	MIN	MAX
GREEN_PAT	Patent applications in environmental domains—OECD Environmental Patent Classification	12,869	7.07	35.06	0	770.0
lGREEN_PAT	Natural logarithm of GREEN_PAT	12,869	0.73	1.19	0	6.6
lPAT	Natural logarithm of patent applications	12,869	2.76	1.92	0	9.3
lNO_GREEN_PAT	Natural logarithm of the residual component of PAT once the environmental ones are subtracted (GREEN_PAT)	12,869	2.68	1.91	0	9.3
lENV_REG	Natural logarithm of OECD Environmental Policy Stringency indicator, moving average in 3 years, country level	12,869	1.25	0.21	0.32	1.6
lDEMAND	Natural logarithm of company sales at constant prices	12,869	7.43	1.99	-0.28	12.9
lRD	Natural logarithm of firm R&D expenditures	12,869	4.39	1.36	0.02	9.5
lDESIGN	Natural logarithm of design applications	12,869	0.53	1.03	0	7.2
lGREEN_DESIGN	Natural logarithm of design applications having an environmental component	12,869	0.12	0.45	0	4.9
lGREEN_TM	Natural logarithm of trademark applications having an environmental component	12,869	0.42	0.68	0	4.8
lTM	Natural logarithm of trademark applications	12,869	1.28	1.22	0	6.2
lTM_sector	Natural logarithm of the share of TM applications in the sector in which a firm operates (at 2 digits)	12,869	1.99	0.52	0	4.0
GD	Dummy equal to one for any positive count in green design, 0 otherwise	12,869	0.09	0.28	0	1.0
lNO_GREEN_DESIGN	Natural logarithm of the residual component of DESIGN once GREEN_DESIGN is subtracted	12,869	0.49	0.98	0	7.1
lNO_GREEN_TM	Natural logarithm of the residual component of TM once GREEN_TM is subtracted	12,869	1.14	1.19	0	6.1

Table 4: Pairwise correlations

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	*lGREEN_PAT*	1.00													
2	*lPAT*	0.65*	1.00												
3	*lNO_GREEN_PAT*	0.60*	0.99*	1.00											
4	*lENV_REG*	0.09*	0.17*	0.16*	1.00										
5	*lDEMAND*	0.46*	0.41*	0.39*	0.02	1.00									
6	*lRD*	0.52*	0.66*	0.66*	0.15*	0.66*	1.00								
7	*lDESIGN*	0.42*	0.51*	0.51*	0.07*	0.37*	0.43*	1.00							
8	*lGREEN_DESIGN*	0.34*	0.33*	0.33*	0.02*	0.21*	0.27*	0.64*	1.00						
9	*lGREEN_TM*	0.42*	0.42*	0.41*	0.11*	0.36*	0.36*	0.45*	0.36*	1.00					
10	*lTM*	0.31*	0.51*	0.51*	0.17*	0.41*	0.46*	0.50*	0.27*	0.65*	1.00				
11	*lTM_sector*	0.01	0.10*	0.11*	-0.10*	-0.02*	-0.02*	0.11*	0.03*	0.11*	0.30*	1.00			
12	*GD*	0.33*	0.34*	0.34*	0.02*	0.22*	0.27*	0.61*	0.84*	0.34*	0.28*	0.04*	1.00		
13	*lNO_GREEN_DESIGN*	0.40*	0.50	0.50*	0.08*	0.36*	0.42*	0.97*	0.49*	0.43*	0.50*	0.11*	0.50*	1.00	
14	*lNO_GREEN_TM*	0.27*	0.48*	0.49*	0.15*	0.38*	0.44*	0.48*	0.23*	0.50*	0.97*	0.31*	0.25*	0.49*	1.00

Figure 1: Distribution of green designs across (and within) Locarno classes



Note: The figure refers to the firms in our sample.

Figure 2: Distribution of the main variables

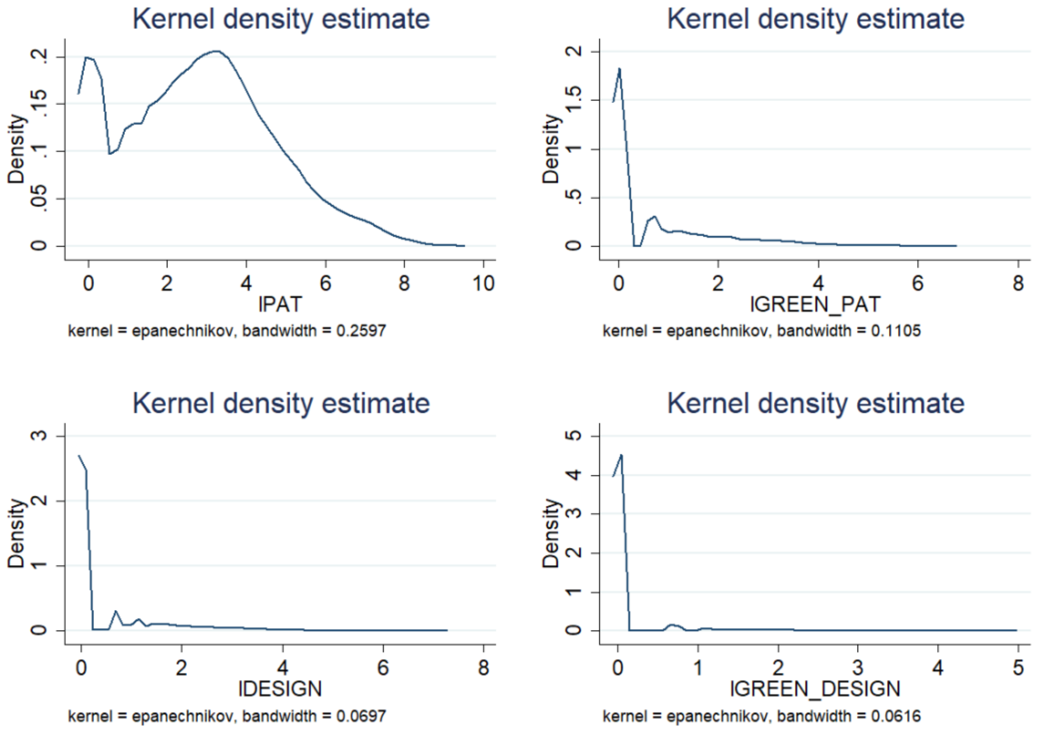
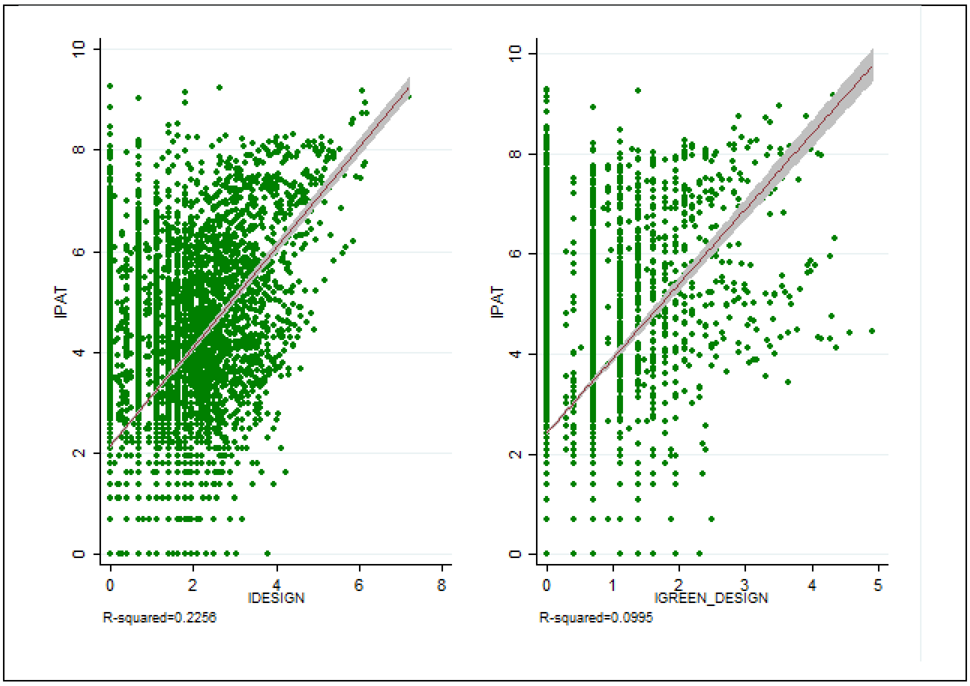


Figure 3: Design, patents, and green patents: scatterplots



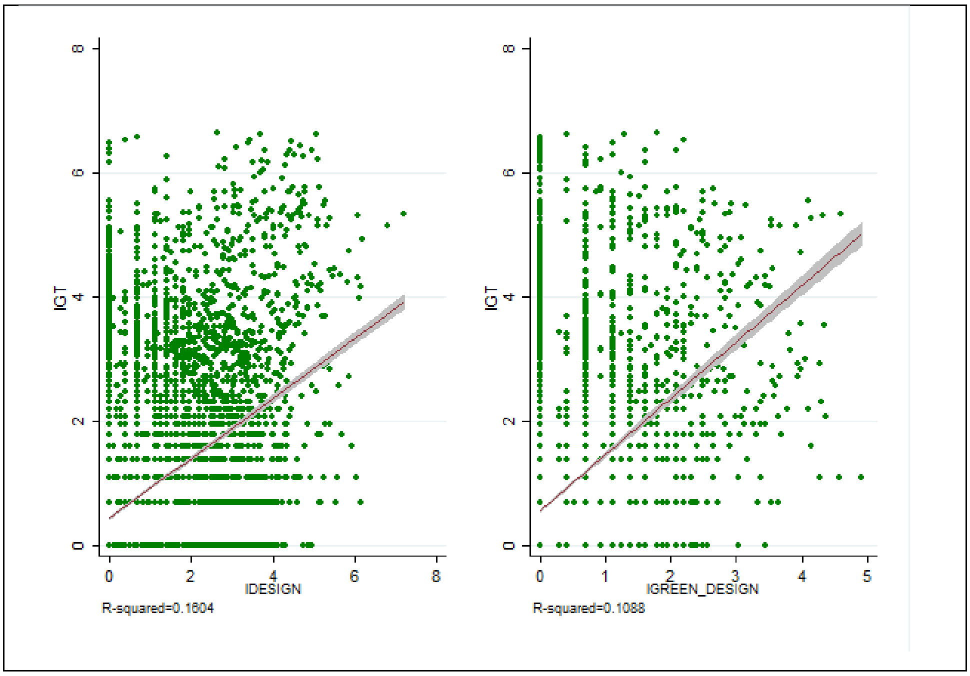

IGT
0
2
4
6
8
IDESIGN
0
2
4
6
8
R-squared=0.1604
IGT
0
2
4
6
8
IGREEN_DESIGN
0
1
2
3
4
5
R-squared=0.1088

Table 5: Determinants of environmental (*lGREEN_PAT*) and non-environmental (*NO_GREEN_PAT*) technologies: seemingly unrelated regression

	(1)		(2)		(3)		(4)	
	lGREEN_ PAT	*lNO_GREEN_ PAT*	*lGREEN_ PAT*	*lNO_GREEN_ PAT*	*lGREEN_ PAT*	*lNO_GREEN_ PAT*	*lGREEN_PAT*	*lNO_GREEN_ PAT*
lDESIGN	0.2298^{***}	0.4102^{***}						
	(0.0091)	(0.0121)						
lDEMAND	0.0438^{***}	0.0099	0.0566^{***}	0.0395^{***}	0.0465^{***}	0.0127	0.0531***	0.0113
	(0.0072)	(0.0096)	(0.0072)	(0.0098)	(0.0071)	(0.0096)	(0.0071)	(0.0096)
lENV_REG	0.4066^{***}	0.9460^{***}	0.4651^{***}	1.0580^{***}	0.4306^{***}	0.9663^{***}	0.4685***	0.9595***
	(0.0423)	(0.0562)	(0.0421)	(0.0576)	(0.0419)	(0.0563)	(0.0418)	(0.0563)
lRD	0.3104^{***}	0.7472^{***}	0.3259^{***}	0.8025^{***}	0.3043^{***}	0.7449^{***}	0.2704***	0.7491***
	(0.0094)	(0.0126)	(0.0093)	(0.0127)	(0.0094)	(0.0126)	(0.0096)	(0.0130)
lGREEN_DESIGN			0.5072^{***}	0.5356^{***}	0.3901^{***}	0.2239^{***}		
			(0.0191)	(0.0262)	(0.0209)	(0.0281)		
lNO_GREEN_DESIGN					0.1361^{***}	0.3623^{***}	0.1197***	0.3603***
					(0.0103)	(0.0138)	(0.0104)	(0.0140)
GD							-0.9692***	0.5335***
							(0.0991)	(0.1338)
*GD*lRD*							0.2780***	-0.0259
							(0.0178)	(0.0240)
Constant	-1.7444^{***}	-3.3455^{***}	-1.9634^{***}	-3.9017^{***}	-1.7680^{***}	-3.3818^{***}	-1.7501***	-3.3779***
	(0.4455)	(0.5928)	(0.4441)	0.0395^{***}	(0.4413)	(0.5932)	(0.4392)	(0.5927)
N	12,869		12,869		12,869		12,869	
R^2	0.449		0.452		0.459		0.464	
Chi^2 *Breush Pagan*	1651.6916		1784.0444		1795.5818		1686.4459	
p-val Breush Pagan	0.00		0.00		0.00		0.00	

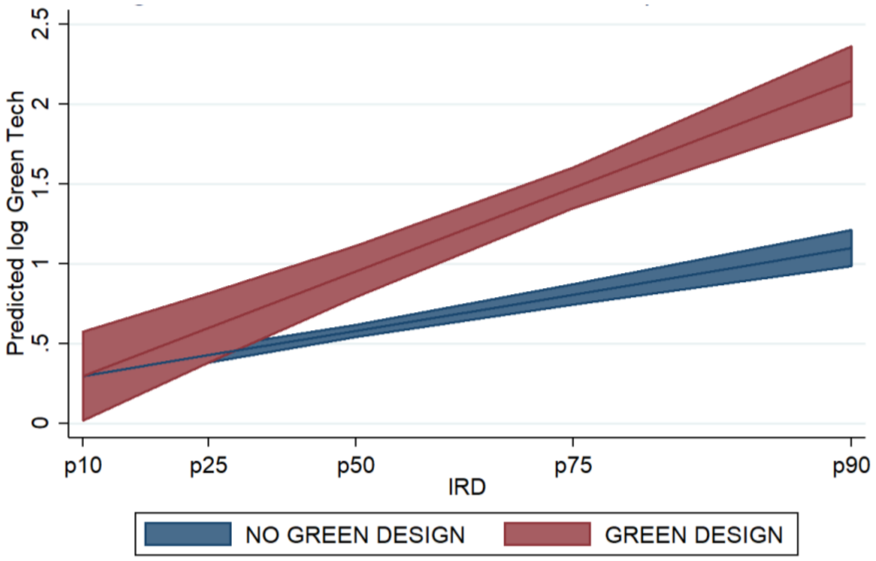
Note: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Sector dummies (as in Table A1) and yearly time fixed effects included.

Table 6: The effect of design (*lDESIGN*) and green design (*lGREEN_DESIGN*) on environmental technologies (*lGREEN_PAT*): panel data analysis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
lDESIGN	0.2548^{***}	0.0550^{***}	0.2914^{***}	0.3229^{***}					
	(0.0270)	(0.0083)	(0.0257)	(0.0581)					
lDEMAND	0.0320^{**}	-0.0009	0.0853^{***}	0.0264^{*}	0.0443^{***}	0.0007	0.0968^{***}	0.0295^{**}	0.0488^{***}
	(0.0149)	(0.0119)	(0.0139)	(0.0150)	(0.0147)	(0.0120)	(0.0137)	(0.0146)	(0.0146)
lENV_REG	0.3338^{***}	0.0277	0.2527^{**}	0.3191^{***}	0.3802^{***}	0.0318	0.3324^{***}	0.3655^{***}	0.4229^{***}
	(0.0798)	(0.0471)	(0.1227)	(0.0785)	(0.0809)	(0.0472)	(0.1213)	(0.0824)	(0.0790)
lRD	0.3177^{***}	-0.0067	0.2906^{***}	0.3012^{***}	0.3447^{***}	-0.0059	0.3086^{***}	0.2844^{***}	0.2970^{***}
	(0.0244)	(0.0119)	(0.0226)	(0.0268)	(0.0252)	(0.0119)	(0.0219)	(0.0297)	(0.0237)
lGREEN_DESIGN					0.4906^{***}	0.0851^{***}	0.7207^{***}	1.3436^{***}	
					(0.0611)	(0.0151)	(0.0568)	(0.2575)	
GD									-1.0496^{***}
									(0.3008)
*GD*lRD*									0.3309^{***}
									(0.0600)
Constant	-1.8937^{***}	0.7766^{***}	-1.794^{***}	-0.5395^{***}	-2.0014^{***}	0.7717^{***}	-2.055^{***}	-1.7183^{***}	-1.8736^{***}
	(0.1634)	(0.1056)	(0.3790)	(0.1966)	(0.1651)	(0.1056)	(0.3741)	(0.1835)	(0.1641)
N	12,869	12,869	12,869	12,869	12,869	12,869	12,869	12,869	12,869
adj. R^2	0.419	-0.110	0.387	0.416	0.415	-0.111	0.397	0.321	0.426
Hansen J statistic				3.4750				2.8062	
p-value of Hansen J				0.0623				0.0939	
Model	OLS, clustered s.e. by firm	Panel Fixed Effects	Panel Between Effects	Instrumental Variables (Instruments: *lTM* and *lTM_sector*)	OLS, clustered s.e. by firm	Panel Fixed Effects	Panel Between Effects	Instrumental Variables (Instruments: *lTM* and *lTM_sector*)	OLS clustered s.e. by id

Note: Standard errors in parentheses, clustered at the firm level for the OLS specification. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Sector dummies (as in Table A1) not included in the panel specification; yearly time fixed effects included.

Figure 4: Marginal effects of the interaction between R&D and design (green vs non-green) on environmental technologies (*lGREEN_PAT*)



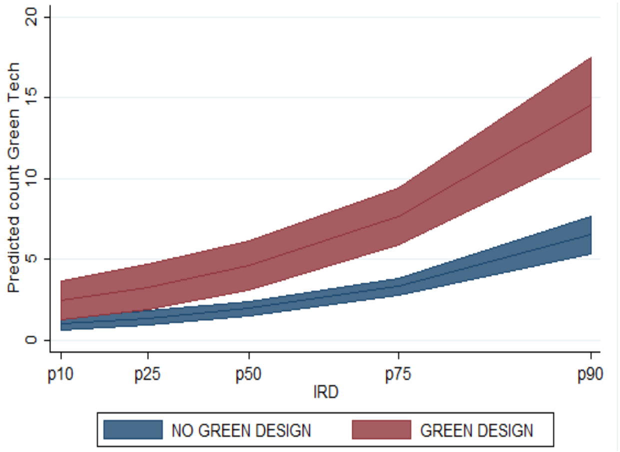
Note: Marginal effects are calculated from specification 9 in Table 6, computed at the 10th – 25th – 50th – 75th and 90th percentiles in the distribution of *lRD*.

Table 7: The effect of design and green design on environmental technologies (*GREEN_PAT*): count models

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DESIGN	0.0062***	0.0049***	0.0005**				
	(0.0013)	(0.0010)	(0.0002)				
lRD	0.7225***	0.6090***	0.1142***	0.7333***	0.6216***	0.1166***	0.7268***
	(0.0249)	(0.0252)	(0.0321)	(0.0245)	(0.0249)	(0.0319)	(0.0258)
lDEMAND	0.1737***	0.1403***	0.1028***	0.1727***	0.1390***	0.1022***	0.1649***
	(0.0199)	(0.0219)	(0.0315)	(0.0199)	(0.0219)	(0.0314)	(0.0198)
lENV_REG	1.6382***	1.0237***	0.1416	1.6396***	1.0336***	0.1571	1.6597***
	(0.1204)	(0.1324)	(0.0963)	(0.1204)	(0.1324)	(0.0962)	(0.1190)
GREEN_DESIGN				0.0454***	0.0344***	0.0065***	
				(0.0081)	(0.0060)	(0.0017)	
GD							1.1756***
							(0.2134)
*GD*lRD*							-0.0780**
							(0.0369)
Constant	-6.7071***	-4.5839***	0.1468	-6.7282***	-4.6187***	0.1177	-6.8215***
	(0.2163)	(0.2331)	(0.2373)	(0.2163)	(0.2330)	(0.2377)	(0.2160)
lnalpha	1.2634***	0.8479***		1.2597***	0.8454***		1.2430***
	(0.0198)	(0.0242)		(0.0199)	(0.0243)		(0.0199)
Inflation equation							
PAT		-0.3082***			-0.3078***		
		(0.0314)			(0.0318)		
DESIGN		0.0110					
		(0.0183)					
lRD		0.6682***			0.6768***		
		(0.0793)			(0.0796)		
lDEMAND		-0.4604***			-0.4579***		
		(0.0412)			(0.0412)		
lENV_REG		0.2648			0.2926		
		(0.2330)			(0.2336)		
GREEN_DESIGN					-0.1288		
					(0.1015)		
Constant		2.6738***			2.5981***		
		(0.4344)			(0.4354)		
N	12,869	12,869	7669	12,869	12,869	7669	12,869
Pseudo R^2	0.1233			0.1237			0.1258
Model	Negative Binomial	Zero-inflated Negative Binomial	Panel fixed effect Negative Binomial	Negative Binomial	Zero inflated Negative Binomial	Panel fixed effect Negative Binomial	Negative Binomial

Note: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Sector dummies (as in Table A1) and yearly time fixed effects included.

Figure 5: Marginal effects of the interaction between R&D and design (green vs non-green) on environmental technologies (*GREEN_PAT*): count models



Note: Marginal effects are calculated from specification 7 in Table 7, computed at the 10th – 25th – 50th – 75th and 90th percentiles in the distribution of *lRD*.

Appendix

Table A1: Industry coverage and main statistics

SECTOR GROUP	SECTOR DISTRIBUTION		GREEN_PAT>0		DESIGN>0		GREEN_DESIGN>0		TM>0		GREEN_TM>0	
	# Firms	%Firms	#	%	#	%	#	%	#	%	#	%
AUTOMOBILES & PARTS	127	6,4%	93	73%	79	62%	40	31%	107	84%	99	78%
CHEMICALS	109	5,5%	100	92%	61	56%	19	17%	104	95%	91	83%
ELECTRONIC & ELECTRICAL EQUIPMENT	172	8,6%	124	72%	110	64%	63	37%	150	87%	135	78%
INDUSTRIALS	236	11,8%	174	74%	163	69%	70	30%	211	89%	189	80%
PHARMACEUTICALS & BIOTECHNOLOGY	239	12,0%	87	36%	63	26%	20	8%	187	78%	69	29%
SOFTWARE & COMPUTER SERVICES	226	11,3%	36	16%	50	22%	18	8%	206	91%	115	51%
TECHNOLOGY HARDWARE & EQUIPMENT	268	13,4%	161	60%	129	48%	63	24%	242	90%	189	71%
OTHER—LOW	220	11,0%	133	60%	74	34%	30	14%	167	76%	137	62%
OTHER—MEDIUM-LOW	127	6,4%	67	53%	69	54%	19	15%	118	93%	93	73%
OTHER—HIGH	161	8,1%	100	62%	122	76%	64	40%	148	92%	124	77%
OTHER—MEDIUM-HIGH	115	5,8%	53	46%	71	62%	33	29%	106	92%	73	63%
WHOLE SAMPLE	**2000**	**100%**	**1128**	**57%**	**991**	**50%**	**439**	**22%**	**1746**	**87%**	**1314**	**66%**

Note: GREEN_PAT>0, DESIGN>0, GREEN_DESIGN>0, TM>0, and GREEN_TM>0 report the share of firms in the sample and in the sector in each row having at least one GREEN_PAT, DESIGN, GREEN_DESIGN, TM, or GREEN_TM in at least one of the years during the period of 2007–2014. Own elaboration on the 2000 firms in the EC-JRC/OECD COR&DIP©.

Table A2: Eco-design product groups from the EC, Internal Market, Industry, Entrepreneurship, and SMEs

- Lot 1 - Professional refrigeration
- Lot 2 – Power transformers
- Lot 3 – Sound and imaging equipment (includes game consoles)
- Lot 4 – Industrial ovens and furnaces
- Lot 5 – Machine tools
- Lot 6 – Ventilation units
- Lot 7 – Steam boilers
- Lot 8 – Power cables
- Lot 9 – Enterprise servers, data storage, and ancillary equipment

Source: https://ec.europa.eu/growth/industry/sustainability/ecodesign/product-groups_en

Table A3: Robustness check: the effect of design (*lDESIGN*), green design (*lGREEN_DESIGN*), and non-green design (*lNO_GREEN_DESIGN*) on environmental technologies (*lGREEN_PAT*)

	(1)	(2)	(3)	(4)	(5)
lDEMAND	0.0346**	0.0335**	0.0217	0.0334**	-0.0009
	(0.0153)	(0.0150)	(0.0146)	(0.0147)	(0.0119)
lENV_REG	0.3407***	0.3694***	0.3577***	0.3518***	0.0290
	(0.0801)	(0.0813)	(0.0864)	(0.0791)	(0.0471)
lRD	0.3255***	0.3005***	0.2523***	0.3123***	-0.0073
	(0.0275)	(0.0317)	(0.0304)	(0.0240)	(0.0119)
lDESIGN	0.2226***				
	(0.0607)				
lGREEN_DESIGN		1.1160***	1.7972***	0.3459***	0.0696***
		(0.3094)	(0.2568)	(0.0591)	(0.0153)
lNO_GREEN_DESIGN				0.1795***	0.0517***
				(0.0298)	(0.0087)
Constant	-1.9279***	-1.7938***	-1.5678***	-1.8814***	0.7749***
	(0.1667)	(0.1909)	(0.1844)	(0.1624)	(0.1054)
N	12,869	12,869	12,869	12,869	12,869
Adj. R^2	0.418	0.364	0.194	0.428	-0.108
Hansen J statistic	1.7463	2.0489	0.4619		
p-value of Hansen J	0.1863	0.1523	0.4967		
Model	Instrumental Variables (Instruments: *lNO_GREEN_TM* *lTM_sector*)	Instrumental Variables (Instruments: *lNO_GREEN_TM* *lTM_sector*)	Instrumental Variables (Instruments: *lGREEN_TM* *lGREEN_TM_sector*	Pooled OLS	Panel Fixed effects

Note: Standard errors in parentheses, clustered at the firm level for the OLS specification. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Sector dummies (as in Table A1) not included in the panel specification; yearly time fixed effects included.

Table A4: Determinants of environmental technologies (*GREEN_PAT*): inverse sine transformation of *GREEN_PAT*

	(1)	(2)	(3)	(4)	(5)	(6)
lDESIGN	0.2452***	0.0521***	0.3305***			
	(0.0250)	(0.0083)	(0.0570)			
lDEMAND	0.0421**	0.0017	0.0339**	0.0560***	0.0030	0.0376**
	(0.0169)	(0.0126)	(0.0171)	(0.0168)	(0.0126)	(0.0166)
lENV_REG	0.3098***	0.0284	0.2919***	0.3537***	0.0318	0.3393***
	(0.0718)	(0.0440)	(0.0705)	(0.0727)	(0.0440)	(0.0744)
lRD	0.3631***	-0.0078	0.3390***	0.3914***	-0.0069	0.3142***
	(0.0273)	(0.0135)	(0.0303)	(0.0279)	(0.0135)	(0.0344)
lGREEN_DESIGN				0.4715***	0.0809***	1.3588***
				(0.0533)	(0.0149)	(0.2514)
Constant	-2.4711***	0.9315***	-0.7709***	-2.6137***	0.9293***	-0.6713**
	(0.1997)	(0.1281)	(0.2416)	(0.2010)	(0.1282)	(0.2680)
N	12,870	12,870	12,870	12,870	12,870	12,870
Adj. R^2	0.413	-0.115	0.409	0.411	-0.116	0.301
Hansen J statistic			2.4555			1.8524
p-value of Hansen J			0.1171			0.1735
Model	OLS, clustered s.e. by firm	Panel Fixed Effects	Instrumental Variables (Instruments: *lTM* *lTM_sector)*	OLS, clustered s.e. by firm	Panel Fixed Effects	Instrumental Variables (Instruments: *lTM* *lTM_sector)*

Note: Standard errors in parentheses, clustered at the firm level for the OLS specification. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Sector dummies (as in Table A1) not included in the panel specification; yearly time fixed effects included.

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