"Un-packing" eco-design:
new evidence on eco-innovation and design
from the Eurobarometer survey

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Abstract

The paper aims at investigating the role of design with respect to the adoption of eco-innovations at the firm level. Going beyond the "packed" account that pervades its analysis in environmental economics, we maintain that an eco-impact of design accrue to firms from their investments in design, even when they are not directly targeted to the adoption of specific eco-design practices. Furthermore, we posit that the eco-impact of design depends indirectly on the way it is used within the firm and on the placement it finds in its business model. Using the Eurobarometer 2015 survey, we test for these arguments with respect to a sample of more than 2700 European and non-European (US and Switzerland) manufacturing firms. Results confirm that investing in design is associated with a greater capacity of eco-innovating, also by making design investments dependent on the way design is used. The effect of design on eco-innovation is positively moderated by the investing firm being young, suggesting this could entail more degrees of freedom in making an alternative (i.e. sustainable) use of design. Eco-innovations could benefit from a wider set of policy and strategic actions than the regulatory support to specific eco-design techniques.

Key-words: eco-design, eco-innovation, design.
JEL codes: Q55; O31; O32.

1. Introduction

The role of design in determining the environmental impact of new products and production processes has been long since recognised. In the literature on new product development, "approximately 80% of a product's environmental profile" has been claimed to be "fixed under the phase of design and concept creation" (McAloone & Bey, 2009, pag. 5). After that phase, the costs of changing product development to accommodate its environmental effects overcome the degrees of freedom for doing it, thus becoming less feasible. Indeed, design can be an important leverage in several environmental respects, like in using materials and energy more efficiently and responsibly in production, in planning the product life-cycle to encourage its environment-friendly use, and in managing the impact of its end-disposal (Burall, 1991).

The environmental use of design, meant as a formal process of designing physical objects, manufacturing processes, and services with an explicit environmental purpose, has found its first conceptualisation with the notion of "eco-design" in the '90s.[1] The notion then rapidly pervaded a number of disciplines out of design studies, like mechanics, engineering and ecology. The notion also entered the realm of environmental economics, where it has enriched with a number of field-specific declinations.[2] On this basis, a specific category of environmentally sustainable business practices (e.g. Life Cycle Assessment (LCA)) and of policy actions have been developed, knowing an important revamp with the recent transition to the circular economy.[3] Indeed, eco-design has become a cornerstone of the new "circular-economy" policy course and of the recent action plans for its development in Europe (EC, 2015; European Environmental Bureau, 2015). Not only can firms design more easily repairable and longer-lasting products, making their materials and components free from hazardous substances, and thus easier to re-use, refurbish and recycle (EC, 2015). They can even "design out waste" (Ellen Macarthur Foundation, 2015), by devising the product components in such a way to fit the cycles of biological (e.g., non-toxic) and technical materials (e.g., polymers), which can be simply composted and re-used more efficiently than with re-cycling.

The normative rationale of these eco-design interventions is that of helping firms internalise the environmental externalities of design, by making them incorporate environmental factors into product creation practices. In so doing, it is somehow taken for granted that design will have an environmental impact for the simple fact of this "integrative" use. In other words, eco-design is thought like to be

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[1] Although the first principles of eco-design can be found in the architectures studies of the 1920s, the first industrial applications of the concept can be found in the early '90s (for an historical review, see Ryan (2003)).

[2] The specifications are indeed numerous and comprehend, among the others, design-for-the-environment (DfE), environmental design, environmentally sustainable design, environmentally conscious design, life-cycle design (see Carrillo et al., 2009).

[3] At least since the early '00's, eco-design has entered the domain of environmental policy in Europe, with the support to the "Integrated Product Policy" (IPP) scheme, which introduced the life-cycle perspective as the new guiding principle for stimulating environmental improvements (Tukker et al., 2010). In the following decade, the European policy for eco-design took up a regulatory vest, translating into two Directives – the Ecodesign Directive (Directive 2009/125/EC) and the Energy Labelling Directive (Directive 2010/30/EU) – in which the eco-use of design is set as mandatory.

ready-available in the firm's environmental tool-box, along with other tools (e.g. green R&D or environmental standards), from which the firm could (be pushed to) draw to increase its sustainability.

In our view, this sort of "packed" way of looking at and promoting eco-design is too simplistic. First of all, it disregards that the eco-impact of design is arguably not invariant with respect to the level of design competencies that firms have acquired, typically by investing in their development. In brief, an effective eco-use of it requires that design is conceived as a strategic intangible asset, in which the firm invests, also and above all to experience its potential environmental benefits. Second, the conventional way of looking at eco-design appears "packed" also for neglecting the role/use design has in the firm's business model – for example, in terms of centrality in the firm's strategy and/or organisational structure – as well as for neglecting a wide set of structural characteristics (e.g. size, age, internationalisation, …) that drive the firm's decision to invest in design and to grasp its environmental benefits. Still in brief, a firm that makes a simple aesthetic (or occasional) use of design might have lower incentives to invest in design and thus a lower capacity to get an eco-impact from it.

All of these aspects make of eco-design something different from an automatic relationship that simply needs to be exploited, and rather suggest us to "un-pack" it in order to devise more effective strategic and policy implications to foster it. In concrete terms, "un-packing" eco-design entails addressing a different research question from "how design can be used environmentally", and rather investigating whether the use of design, *per se*, can actually be a driver of technological innovations with a favourable environmental impact.[4] This is the aim of this paper, which intends to investigate the role of design as an intangible asset to drive the firms' opportunities and capacities of eco-innovating. More precisely, its objective is to focus on design investments and, by controlling for their determinants and for the entailed risk of reverse causality, looking at their effect on the firm's propensity to adopt environmentally sustainable technologies.

Addressing this research question requires two novel methodological approaches to the analysis of eco-design, which represent the main elements of originality of the paper. From a theoretical point of view, "un-packing" eco-design involves going beyond the "black-boxed" treatment it has so far received in environmental economics, and to integrate it eclectically, as we will do: on the one hand, with the scarce, but emerging literature on the management of eco-design in business studies; on the other hand, with the insights recently obtained on the relationship between design and innovation in general, and between design and eco-innovation in particular. "Un-packing" eco-design has also implications in terms of empirical analysis, as it requires enriching the typical case-study approach through which the environmental literature has so far tried to illustrate specific instances of environmental integration in design. If the actual proof of the eco-impact of design is searched for rather than assumed, systematic

[4] While eco-design does represent a specific and purposeful environmental use of design, our objective is to investigate whether design can have an eco-impact getting used introductorily, complementary, or even irrespectively from the deliberated adoption of a codified eco-design technique or procedure.

evidence on both environmental performances and design practices need to be used, such as that offered for the first time by the 2015 Eurobarometer survey[5], on which we base our empirical application.

Using a sample of about 2700 manufacturing firms, for the 28EU countries plus US and Switzerland, observed with respect to the period 2012-2014, we estimate a battery of standard and bivariate recursive probit models, in which the propensity to adopt new sustainable technologies depends on their investments in design, and in which these investments are in turn affected by some consistent design drivers and by a set of proper controls.

Results confirm that investing in design is associated with a greater capacity of eco-innovating, apparently more than for other standard eco-innovation drivers, and also when controlling for a possible reverse causality. In addition to a theoretically consistent set of determinants contained in the Innobarometer 2015, these investments actually depend on the way design is used within the firm, which thus also matters for eco-design. Finally, the effect of design for eco-innovation is positively moderated by the investing firm being young rather than old, suggesting this status could entail more degrees of freedom in making a new and alternative (i.e. sustainable) use of design. All in all, with these specifications, design appears to have an "eco-effect" (ex-post) in addition to that entailed by its deliberated "eco-use" (ex-ante). These results have important strategic and policy implications. Eco-innovations could benefit from a wider set of policy and strategic actions than the support to and adoption of specific eco-design regulations and techniques, respectively, like those related to design driven innovations and to design-based business models.

The paper is structured as follows. Section 2 positions our analysis of eco-design with respect to the extant literature. Section 3 presents the dataset and the econometric strategy of the empirical application. Section 4 illustrates its results and Section 5 concludes.

2. Background literature

The scientific debate on the concept of eco-design is nowadays very intense in different disciplines.[6] However, its economic analysis is still dispersed and marked by heterogeneous degrees of "compactness".

In environmental economics, eco-design is mainly meant as synonymous of "integration" into product development of an environmental dimension, which over time has evolved from the reduction/increase

[5] Although an updated version of the Innobarometer has been realized during the time of this writing (Innobarometer 2016), the idea of the present paper was incubated and first developed when the data of the Innobarometer 2015 were the only ones available. The replication of the analysis with respect to this last wave, possibly in a comparative framework, represents of course a future step on our research agenda.

[6] Since the early 00's, at least two journals - The Journal of Sustainable Product Design (Kluwer Academic Publishers) and The International Journal of Sustainable Design (Inderscience Publisher) – regularly host dedicated research contributions, which mainly address the technical aspects of its implementation. While admittedly multidisciplinary, these journals actually gravitate in the orbit of mechanical engineering and design studies.

of environmental overloading/efficiency, through the implementation of a green image and brand name, up to the realisation of a circular economy (Karlsson and Luttropp, 2006, Braungart et al., 2007). Most of research is based on coupling design/engineering principles with environmental sciences, and has so far resulted in a wide and technical literature about: [7] meta-approaches to eco-design – e.g. "Case-Based-Reasoning" (CBR) vs. "Inventive Problem Solving" (TRIZ) (Yang and Chen, 2011) – specific systems of eco-designing – e.g. "human powered systems" (Jansen and Stevels, 2006), "product life time optimisation systems" (Nes and Cramer, 2006), and "cradle-to-cradle design systems" (Braungart et al., 2007) – and batteries of eco-design techniques – e.g. Life Cycle Assessment (LCA), design for the environment (DfE), product take-back and stewardship (Knight and Jenkins, 2009), just to mention a few.

The economic analysis of these eco-design aspects has led to important results. In particular, their environmental impact has been shown to depend on the actual timing of their implementation during the product-life-cycle (e.g. Luttropp and Lagerstedt, 2006) and on the specific kind of products to which they are applied (e.g. Vezzoli and Sciama, 2006). Furthermore, a series of trade-offs have been identified with respect to their combined implementation (e.g. Byggeth and Hochschorner, 2006). On the other hand, these are generally results of qualitative studies and/or of quantitative analyses, either based on case-studies (e.g. Cerdan et al., 2009) or on limited samples of firms (e.g. Santolaria et al., 2012), which make their extension and generalisation hard to draw. What is more, from a conceptual point of view, in this stream of literature design is somehow assumed to be the "door" through which the integration of environmental consideration intro product development occurs. Rather than on the design capacity of being actually so, the focus is rather on the "keys" to open such a door and make the integration happen.

The analysis of eco-design appears less "black-boxed" in the growing literature on eco-innovations at the firm level. Here design has been investigated - although less intensively than in the previous stream - as one of the different drivers through which firms could introduce new products and/or processes with a favourable environmental impact.[8] Indeed, eco-design does not amount to the "simple" eco-use of design by firms here, but rather as a potential relationship between: on the one hand, design – meant as an intangible asset, providing firms with knowledge and competencies about the functionalities of their production/organisational processes, and about their products and aesthetics; on the other hand, eco-performance – specified through those gains of environmental sustainability firms can reach by innovating.

In addressing such a relationship, research on eco-innovation has obtained important results in two respects. In a first respect, it has pointed out a variety of mechanisms through which design could eventually entail a higher capacity/propensity to eco-innovate, in addition to those "guaranteed" by the

[7] As appears evident from the quoted references, the bulk of this literature has so far appeared in the Journal of Cleaner Production.

[8] More in general, following Kemp and Pontoglio (2007, p. 10), eco-innovations can be defined as "the production, assimilation or exploitation of a product, production process, service or management or business methods that is novel to [firms] and which results, through-out its life-cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives".

use of eco-design tools. Following the "regulatory push-pull effect" (Horbach et al., 2012), a first mechanism has been identified in the policy enforcement of design as a driver of eco-innovation, by recommending its eco-use through dedicated environmental directives (e.g. eco-labelling and energy-labelling) (Ghisetti and Pontoni, 2015; Triguero et al., 2010). More recently, other extra-regulatory mechanisms have been recognised by extending the resource-based view of the firm to the firm's capacity of eco-innovating. For example, design has been suggested to be a strategic instrument to increase product complexity and thus the appropriability of eco-innovations' returns (Horbach et al., 2013). Design investments, along with other non-R&D based ones, have been also found to be a significant source of knowledge for an "informal" mode of eco-innovating, which is based on Doing, Using, and Interacting (DUI), rather than on Science, Technology, and Innovation (STI) (Marzucchi and Montresor, 2017). Looking at different typologies of eco-innovation, design also appeared an important dimension to increase their environmental impact – from "component additions", to "sub-system", and "system changes" – by crossing their degree of novelty (i.e. incremental vs. radical) with the kind of environmental impact (i.e. reducing negative and increase positive) firms intend to pursue (Carrillo et al., 2009).[9]

The second respect in which research on eco-innovations has contributed to eco-design is empirical. In addressing the previous mechanisms, along with other ones, a number of micro-data sources (e.g. the latest editions of the Community Innovation Survey (CIS) and of the Eurobarometer, and the analysis of so called "Green" Patents) have been used and investigated through sophisticated econometric techniques, leading to a more systematic analysis of eco-design than with case-studies.[10]

In synthesis, the literature on eco-innovation has reached a less "compacted" analysis of eco-design than standard environmental economics, to which this paper intends to contribute. In particular, we aim at pursuing a wider and more focused analysis of design as a driver of eco-innovation, which makes a further step towards the "un-packing" of eco-design, by looking more carefully at its business dimension. In so doing, we draw on and extend another field of studies on eco-design, which has looked at the organisational pre-conditions for the integration of environmental aspects into product development.

Rather than on "hard" design techniques, this literature actually focuses on the "soft-side of eco-design" (Boks, 2006) and points to a variety of business-related aspects, which are responsible for an innovative-sustainable impact of design. In addition to socio-psychological and emotional attitudes towards the implementation of eco-design – like for example the cooperation spirit between its proponents and its executors (Boks, 2006) – these aspects deal with how firms organise to make of design an eco-innovation driver. First of all, design can have such a role if firms invest resources in its development. In general terms, by allocating time and money to design projects, firms formally commit

[9] For example, 'end-of-pipe' technologies are designed as "component additions" as they consist of additional components (incremental) to reduce environmental pollutions (negative). On the opposite extreme, circular (i.e. closed) production cycles, for example in textiles, have the design of a "system change", as they target both positive and negative environmental impacts through radical interventions (Carrillo-Hermosilla et al., 2009).

[10] The majority of the studies to which we have referred actually investigate large samples of firms for one or more countries at the time, sometimes by also using a dynamic setting and panel techniques.

to increase and improve the understanding of their products' functionalities/aesthetics and of the basic operations of their production processes. In this way, they can augment their creativity in both respects, attain higher capacities of coupling their technology with the customer needs, and increase their innovation propensity (Tether, 2006). Systematic evidence of an impact of design investments has been found only on "standard" innovations so far (Galindo-Rueda and Millot, 2015; Montresor and Vezzani, 2016; 2017). However, we can expect a similar effect also on the firm's propensity to eco-innovate. Through design investments, even when they are not explicitly targeted to the development/adoption of formal eco-design practices, firms could discover new technological opportunities and solutions with a favourable environmental impact. Of course, should the design investment be directed to the implementation of specific eco-design techniques, the impact could be expectedly greater and/or more immediate. However, design (investments) could work in an eco-manner also by stimulating firms to develop a creative thinking towards "naturally enterprising" and "greening of business products" (Beard and Hartmann, 1997), as well as to favour a "transition management" towards sustainable innovations (Mulder, 2007).

A second organisational aspect of eco-design to which the literature has paid attention is the position of design within the firm. Linking design with environmental abilities actually requires the firm to set the former at the centre of both multi-disciplinary teams and external partnerships for the realisation of eco-innovation (Carrillo et al., 2009; Braungart et al., 2007). As revealed by documented case-studies, successful eco-design projects usually rely on the constitution of dedicated organisational platforms for their development, which are placed at the core of the firm's business model (Johansson and Magnusson, 2006; Tingström et al. 2006). More in general, the transition towards such a "sustainability-driven business model", based also and above all on eco-innovations, entails that design and designers keep a pivotal role in setting the firm's strategy and priorities (Esslinger, 2011). Drawing on this latter stream of literature, we expect that the firm's propensity to eco-innovate increases by increasing the "complexity" of the use of design within it, and with the "centrality" design is accordingly given in the firm's business model (Montresor and Vezzani, 2017). To be sure, as we will say in the empirical application that follows, the use of design within the firm could also affect the extent at which firms decide to invest in its development: for example, in case design is mainly used by the firm for enhancing appearance and attractiveness of the final product, its propensity of investing in design would be lower than when design is an integral component in the company's strategy.

3. Empirical application

3.1. Data

Our empirical analysis refers to a sample of more than 2700 European and non-European (US and Switzerland) manufacturing firms, of virtually any size, from the Flash Eurobarometer-415 on "The Innovation Trends at EU Enterprises": in brief, the Innobarometer 2015 (http://www.designforeurope.eu/innobarometer-2015).[11] This is a "flash" kind of survey containing firm-specific information with respect to the period 2012-2014 on a variety of aspects, such as: different typologies of innovation, including eco-innovations; innovation drivers, obstacles and performances; tangible and intangibles investments; specific highlights on both policy and company features, among which, those of interest for our study, that is, design investments and the use of design within the firm.

In order to avoid the risk of systematic response-biases (see Montresor et al., 2014), the majority of the survey questions are of qualitative nature and consist of categorical and/or dichotomic information. More precisely, the Innobarometer 2015 tries to infer the presence of eco-innovations by surveying the firms' adoption and plans of adoption (in the following year) of sustainable manufacturing technologies. On the other hand, design investments are captured through a "categorical" question on tangible and intangible investments, taken and adapted from the previous Innobarometer 2013, in turn inspired by the NESTA intangible survey for the UK (see Montresor and Vezzani, 2016). Similarly, the questions on the firm's innovation outcomes and on its innovation-related performance are adapted from the Community Innovation Survey (CIS). Finally, with respect to the use of design, the relative question has been built up by drawing on the so-called "ladder model", according to which, the role that design potentially plays within the firm can be ordered hierarchically from no design use, to more integrated and sophisticated uses in the firm: a model that has been implemented and tested by Statistics Denmark within its latest R&D and innovation surveys (for 2010 and 2012) (see Galindo-Rueda and Millot, 2015, p. 27). In so doing, the question on the use of design is based on the "open" definition approach typical of the Innobarometer survey, as opposed to the detailed instructions for definitions adopted by the CIS. An important benefit of this approach is that it does not impose a specific view on design (as well as on innovation) upon the respondents, which may perceive it differently according to the industry they operate, while the main cost is a lack of preciseness of the answers.

The nature of the Innobarometer 2015 questions does require caution in the empirical analysis. Similarly, special care is required by the cross-sectional nature of the questionnaire, which prevents us from considering the results of econometric analysis as more than significant correlations. On the other hand, the survey has a quite interesting and wide coverage of aspects, which also enables us to control for problems of unobserved heterogeneity to a certain extent.

3.1. Variables and econometric strategy

As we said, our focal *dependent variable* is the firm's adoption of eco-innovations, *EI*. This is proxied by a dummy, which takes value 1 if the firm has already adopted and/or plans do adopt sustainable manufacturing technologies (using energy/materials more efficiently and drastically reduce emissions) in the very next future (next year), and 0 otherwise.

As for the *independent variables*, following the standard approach to eco-innovation drivers, based on the interplay between "regulatory push/pull effect", "demand", "technological conditions", an

[11] The survey does also cover a number of non-manufacturing and services industries, which we have however excluded as one of our focal variables (on eco-innovations) has been posed only to manufacturing ones.

“firm-specific factors” (see Horbach et al., 2012), we first try to account for their adoption with a regulatory kind of variable. Unfortunately, the Innobarometer 2015 is poorly endowed in this respect, and forced us to refer to Eurostat data for plugging in the analysis a standard environmental regulatory variable, but at an aggregated level of analysis: the expenditure on environmental protection by country-sector in the survey period, *REG2014*. In accordance with a resource-based view of the EI determinants (see Marzucchi and Montresor, 2017), we then try to consider the firms’ capabilities of eco-innovating. First, we insert in the analysis the most diffused proxy of their technological determinants, represented by their expenditure in Research and Development: a dummy, *RD*, which takes value 1 if firms have a positive share of turnover invested in such an activity, and 0 otherwise. In the same respect, we control for other innovative investments than R&D with a dummy, *HIGHINNO*, taking value 1 the firm highly invested in innovation activities (i.e. more than 11% of its turnover). The set of standard EI regressors is completed by some structural features of the sample firms, usually referred in the literature as “firm specific factors”, such as: their size, proxied by the Log of the number of their employees, *LSIZE*; their age, proxied by their being young (founded after January 2014) through a dummy, *YOUNG*; their belonging to a group, still with a dummy, *GROUP*; and their degree of internationalisation, as revealed by the percentage of their turnover from sales in EU or other countries out of their own, *INTERNATIONAL_sales*, which allows controlling for “demand conditions” to EI.

Our research hypotheses about the role of design for eco-innovation (see Section 2), are tested by augmenting the previous array of drivers in two respects. On the one hand, we consider whether firms have an economic significant engagement in design investments, by building up a dummy, *DESIGN_inv*, assuming value 1 if they allocate to them a positive share of their turnover.[12] On the other hand, we refer to the use of design within the firm by exploiting the “ladder model” adopted by the Innobarometer 2015. Following this model, firms have been asked to “describe the business activities with regards to design”, apart from the benchmark one (“Design is not used in the firm, it is not relevant”, *DESIGN_NOT_USED*). These categories/dummies range from a “non-systematic” use of design (*DESIGN_NOT_SYST*), to a merely “aesthetic” function (*DESIGN_AESTHETIC*), an “integral” recognition of its manifold functionalities (*DESIGN_INTEGRAL*), up to a “central” role for the firm’s business activities (*DESIGN_CENTRAL*). Of course, these items have a very limited informative value of the extent at which design is embedded in the firm’s business model, to which the respondents have not been asked to refer in order to avoid the risk of systematic biases in its understanding. On the other hand, the same categories are at least suggestive of a way of conceiving the role of design within the firm, which could be retained non-independent from its management and positioning in the business model itself.

Once introduced the previous design-related variables, a final augmentation of the model is obtained by looking at the role that firm size and age could have in moderating the impact of design investments on eco-innovations, with different possible outcomes. Drawing on some recent research (see Leoncini et al., 2017; Marzucchi and Montresor, 2017), we actually expect that being large rather than small could entail different problems in the firms’ exploitation of their intangibles for getting green: e.g.

[12] Unfortunately, the Innobarometer 2015 does not distinguish the design investments that are directed to the introduction of specific eco-design practices, which could however be included in the *DESIGN_inv* variable (see Section 2).

administrative/organizational complexity vs. too low scale of design use. Similarly, we can expect that being young (old) could allow firms more degrees of freedom (experience) for integrating environmental considerations in design. Accordingly, the model is augmented by two interaction terms, between *DESIGN_inv*, and *LSIZE* and *YOUNG*, respectively, which are intended to capture whether the eco-impact of design is positively or negatively moderated by them.

Insert Table 1 around here

Using the previous set of variables (see Table 1, for their definition and descriptive statistics), in a baseline specification we first estimate an EI-adopted knowledge production function, augmented with the role design. In particular, given the dichotomic nature of our y_1 dependent variable, *EI*, we estimate the following probit model:

$$P(y_1 = 1|\, D, X, Z) = \Phi(D'\beta_1 + X'\beta_2 + Z'\gamma) \qquad (1)$$

where Φ is a standard cumulative normal function, *D* the vector of our five design related variables, in terms of investments and position within the firm, *X* and *Z* the (other) EI determinants and firm-specific controls we have been able to capture, respectively for the "regulatory push-pull", for "technological conditions", for "demand conditions" and for "firm specific factors" as well as country and sector dummies.

At the outset, the estimation of (1) can provide us with some first insights on our research questions. In the same respect, Table 2 shows that collinearity is not an issue in doing that. Additionally, the variance inflation factor, computed to spot the presence of multicollinearity in the covariates, is close to the lower bound of 1 for most of the variables and it is always lower than 1.5 for all the covariates, with the exception of country and sector dummies reporting higher values, which are however always lower than 2.5. Overall, the mean VIF is 1.75. This would support the absence of multicollinearity issues in our models.

Insert Table 2 around here

A more accurate and efficient estimation of the eco-impact of design requires us to consider the possible endogeneity of the firm's decision to invest in it. In particular, a problem of reverse causality could be latent, as design investments might be spurred by the adoption of eco-innovations, rather than the other way round. In order to tackle this issue, we thus estimate a recursive bivariate probit (Greene 2008, Maddala, 1983), which separates our two sets of design-related variables in the light of their different nature, and tries to make design investments exogenous before looking at their impact on eco-innovation.

As discussed in Greene (2008) the class of bivariate probit models is a natural extension of the probit ones, which allows for two equations having correlated disturbances. In our case, the model adopted is a specific case of bivariate probit, with recursive simultaneous-equations, given that *DESIGN_inv is*: on the one hand, among the determinants of the outcome variable of interest (*EI*); on the other hand, the dependent variable of a first reduced form equation for dealing with its potential endogeneity. The following recursive bivariate probit is thus estimated:

$$P(y_1=1, y_2=1 | x_1, x_2) = \Phi_2(x_1'\beta_1 + \gamma y_2, x_2'\beta_2, \rho) \qquad (2)$$

where the dependent variables are, y_1 = *EI* and y_2 = *DESIGN_inv*.[13]

As far as the regressors are concerned, x_1 comprehends the same *X* and *Z* variables of Equation (1). As for x_2, we account for the firm's decision to invest in design, *DESIGN_inv*, using a set of theoretical consistent determinants, moving progressively from a reduced form with only core variables, to an extended form. As for the reduced form, along with standard Country and Sector dummies, we retain that the different specifications of the role of design along the design ladder could be of high relevance in this respect, as anticipated in Section 2. Consequently, we expect that the absence of design use (*DESIGN_NOT_USED*) should have a negative impact on the decision to invest in it: at the lowest step of the ladder, when design is not relevant to the firm, one would expect that the firm uses its resources alternatively. Still in the reduced form, we also expect that design investments should be spurred by the successful implementation of design-related activities, such as the market testing of a product or service before launch, about which the Innobarometer enables us to build up a dummy, *MKT_TESTING*, in case of an effective public support to it.

This first reduced form is then augmented in two steps. First, we expect that the international and/or innovative profile of the firms could also affect their need and/or opportunities to invest in design, and we thus regress *DESIGN_inv* against *INTERNATIONAL_sale* and *HIGH-INNO*, respectively (see Table 1). Second, we draw on the Innobarometer 2015 an additional set of useful info, which can be useful to move closer to a proper investment function. On the one hand, we expect that design investments are correlated with market performance, as depending on it firms could have additional (or lower) resources to finance their undertaking: accordingly, we consider a battery of dummies which refer to different kinds of change in the firm turnover (*TURN GROWTH > 25%*, *TURN GROWTH 5% to 25%*, *TURN UNCHANGED*, *TURN LOST 5% to 25%*, *TURN LOST > 25%* - see Table 1). On the other hand, we retain that design investments could be urged by the attempt at overcoming eventual problems in design-related activities, like weak distribution channels, hampering the commercialization of innovative goods or services, still captured by a dummy, *WEAK_DISTR*.

Finally, as a final control of our *DESIGN_inv* equation, we ultimately replace the *DESIGN_NOT_USED* variable with the other variables about the use of design within the firm. Staying at progressively higher

[13] As recommended by Chiburis et al. (2012), we estimated the recursive bivariate probit by bootstrapping standard errors as our sample size is limited, namely lower than 2800 observations.

steps of the design ladder, and giving design a progressively more important role within the firm's organisation and business model, would possibly demand higher design investments. Accordingly, we insert the relative variables for a progressively more central use of design (i.e. *DESIGN_NOT_SYST*, *DESIGN_AESTHETIC*, *DESIGN_INTEGRAL*, and *DESIGN_CENTRAL*).

Consistently with the logic of the model, while estimated against the previous regressors in the first step, *DESIGN_inv* enters recursively in the second step of it, to explain the firm's propensity to eco-innovate. Indeed, should the relative tests actually signal a problem of simultaneity bias (see Section 3), this procedure would enable us to avoid distorted results in the analysis of eco-design. In doing that, the second step of the model does also comprehend the other EI determinants and controls that we have identified above (see Table 1).

Before turning to the results, it should be observed that Maddala (1983) discussed the need of an exclusion restriction in the second equation, as necessary for identification of this model. Wilde (2000) shows instead that in recursive multiple equation probit models with endogenous dummy regressors, no exclusion restrictions for the exogenous variables are needed when the condition of sufficient variation in the data is met. More recently, Mourifie and Meango (2014) challenged the Wilde (2000) criterion and prove the necessity of an exclusion restriction to ensure point identification in this model. In light of this discussion, we chose to make sure to have at least an exclusion to be sure allowing for the identification of parameter estimates. That was quite straightforward as *REG2014, GROUP ,YOUNG and LSIZE* do only enter x_2, i.e. the vector of covariates of second equation, whereas *DESIGN_NOT_USED*, *MKT_TESTING*, the categories of turnover growth and *WEAK_DISTR* do only enter x_1.

4. Results

A first set of results about the role of design for eco-innovation is provided by the probit estimation of Eq.(1) (Table 3). In its baseline specification (Column (1)), which controls for the basic structural features of the sample firms (*LSIZE* and *YOUNG*), and for two of its main drivers (*RD* and *REG2014*), design investments significantly and positively correlate with EI. Consistently with previous studies (see Ghisetti and Pontoni, 2015), larger firms do have an advantage in eco-innovating, while age does not have a distinguishing impact for it, as found already in previous studies (e.g. Horbach, 2008). R&D is also confirmed as a significant EI determinant, while the aggregate way we tried to control for regulations does not. In this relatively consistent picture, having an economically recognizable investment in design (>1% of turnover) is significantly associated to firms with a higher propensity to eco-innovate and thus supports our main research hypothesis: design turns out to be eco, when firms allocate resources to its development, even irrespectively from the formal adoption of eco-design techniques.

Insert Table 3 around here

The eco-effect of design persists by augmenting the model with the progressive insertion of other candidate drivers and controls - *INTERNATIONAL_sales* (Column (2), *GROUP* (Column (3), and

HIGHINNO (Column (4). Out of them, a significant effect emerges only from the presence of other high innovative investments (*HIGHINNO*) in addition to *RD* and *DESIGN_inv*, confirming previous evidence on the "costly" nature of the eco-innovating process (Gagliardi et al., 2016). Last, but not least, design investments keep their highly significant correlation when the use of design along the ladder is controlled for (Column (5)). Quite interestingly, and still consistently with our expectation, the only specification in the use of design that turns out significant is the one that alludes to its centrality within the firm (*DESIGN_CENTRAL*): in line with the organizational literature on eco-design, the integration of design and environmental capabilities seems to call for a pivotal role of design within the firm.

The previous results find further interesting specifications when their marginal effects are calculated (Table 4).

Insert Table 4 around here

Not only does design correlate significantly with EI, but its marginal effect on it appears even greater than that of the investments in R&D, and similar to that of the other high innovative investments (*HIGHINNO*). Thinking about the prime role of driver that R&D is usually recognised in innovation and eco-innovation studies, this result appears of great importance: consistently with early innovation economics (Walsh et al., 1992; von Hippel, 1998), design could surpass the innovative power of R&D by allowing firms to discover the customer and market potential of new product development. On the other hand, marginal effects also show that the centrality of design within the firm appears of even greater importance than design investments for the adoption of EI: also with respect to EI, as for standard innovations (Montresor and Vezzani, 2016), the innovative value of this intangible asset relies on the way it is managed more than on the amount of resources invested in it.

Turning to the analysis of the moderation effects of *YOUNG* and *LSIZE* (column (6) and (7)), further interesting insights emerge. As the sign of the interaction term coefficient might not correspond to the direction of the effect, and the statistical significance of the effect cannot be directly assessed from Table 4 (see Zelner, 2009 for a discussion), we have followed the Ai and Norton (2003) and Norton et al. (2004) approach to visualize the "correct" interaction effect, which is displayed in Figure 1 with respect to *YOUNG* and Figure 2 with respect to *LSIZE*.[14]

As for the first moderation effect, it emerges that the mean interaction effect is always positive (first side of Figure 1) and generally significant (second side of Figure 1) although the significance varies across firms. Considering that *YOUNG*, in isolation, is not significant (see Table 4, column (1), this finding seems to suggest that being young matters only as it presumably give firms more "degrees of freedom" than older ones, in directing their design investment towards environmental sustainability: degrees of freedom that a longer experience with a possibly standard (e.g. non-green) use of design could actually reduce given the relevance of path-dependence phenomena.

[14] This why Table 4 only reports marginal effects for the first 5 columns, as the interaction effects are better captured through the ad hoc analysis reported in Figure 1 and Figure 2.

Recalling that LSIZE is a significant driver for EI (see Table 4, column (1)), Figure 2 shows instead that in most of the cases the moderation effect is negative but statistically not significant (second side of Figure 2). In other words, it seems that no moderation effect is at stake when the role of size is considered: larger firms are "simply" more eco-innovative.

All in all, probit results already provide general support to our research hypotheses about the eco-role of design. However, as we said in the previous Section, their holding could be affected by the endogeneity of our focal regressor, *DESIGN_inv*. Indeed, when a bivariate probit is applied to address this problem, along the lines described in the previous section, evidence of a simultaneity bias actually emerges. Given that ρ measures the correlation in the disturbances of the two equations, it emerges that the two equations cannot be treated as isolated (Greene, 2008). The Wald statistic for the test of the hypothesis that ρ equals 0 cannot be rejected in all our estimation result. As for the goodness of the fit, a Rao score test is performed to detect whether our models are miss-specified and thus estimations are inconsistent or not[15]. This test does not reject the goodness of fit for all our specifications.

The choice of a bivariate probit is thus motivated. What is more, its results appear generally consistent with our expectations (Table 5)

Insert Table 5 around here

Results in Table 5 are reported in the order previously discusses with respect to the second equation aimed at estimating the determinants of EI. As for the first equation, as we already said, in order to provide robustness to our findings, we have adopted a rule that starts from a reduced form of it, in which only the second equation is extended (columns (1) to (6)), to a progressive extension of the first equation towards columns (7) to (9). As we said, the reduced form model for the first equation accounts for two variables along with country and sector dummies: the absence of design relevance within the firm (*DESIGN_NOT_USED*) and the presence of a successful approach to market testing (*MKT_TESTING*).

Starting with the results of the first equation (lower panel of Table 5), as expected, design investments turns out negatively correlated with the absence of design relevance within the firm (*DESIGN_NOT_USED*). On the one hand, design investments are higher for firms having a successful approach to market testing (*MKT_TESTING*).

Looking at the other arguments of the design investment function we have been able to address with the Innobarometer 2015, results are only partially confirmed. Operating on international markets (*INTERNATIONAL_sales*) is still mostly not significant, while relevant is again the effect of high investments in innovation (*HIGHINNO*), which thus seem complementary to design investments. A positive market performance of the investing firm matters, but providing it is moderate (*TURN GROWTH 5% to 25%*): firms with the highest turnover growth (*TURN GROWTH > 25%)* instead seem

[15] This test is performed using the Stata postestimation command `scoregof` developed following the Murphy (2007) to compute the goodness of fit score test applicable to bivariate probit models (Chiburis 2010, Chiburis et al. 2012)

to move away from design investments to other resource allocations, suggesting that design could be substituted with other strategic drivers (i.e. other intangibles) in growing at fast rates. Finally, the explanatory role of the design-related activities we have been able to capture turns out to be confirmed. Not only MKT_TESTING remains significant, but, on the other hand, design investments are also more likely to occur for firms for which design investments could be a mechanism to overcome problems of weak distribution channels (*WEAK_DISTR*).

Lastly, as for our ultimate extension in column (9), our argument about the "structural" position of design in the firm's business model in accounting for design investments gets also confirmed: a simple, non-systematic use of design (*DESIGN_NOT_SYST*) does not emerge significant yet, while a progressively more integral use of design after that level (*DESIGN_AESTHETIC*, *DESIGN_INTEGRAL*, and *DESIGN_CENTRAL*) is associated with larger and larger design investments.

Overall, we can conclude that the predictors we have identified to make design investment exogenous work relatively well. On this basis, we can more safely look at the effect of design investments in accounting for eco-innovation in the second step of the model (upper panel of Table 5). The results that we got are even more reassuring than the previous ones: having controlled for a risk of reverse causality, eco-innovations could be claimed driven by the firms' investment in design. Allocating time and money to design projects could possibly increase the firms' familiarity with eco-design techniques and practices and push them towards their adoption. However, as the kind of projects to which our variable refers are presumably of a wider domain, and not necessarily with this specific target, it seems that design could more generally work as a channel through which firms can increase their creative thinking in the green realm (Beard and Hartmann, 1997).

Once again, the significance of design investments is kept when the augment the baseline specification (including *SIZE*, *YOUNG*, *RD* and *REG2014*) by including the other remaining regressors (*INTERNATIONAL_sales*, *GROUP* and *HIGHINNO*). On the other hand, having controlled for the endogeneity of *DESIGN_inv*, and having moved the use of design among its determinants, some interesting changes occur with respect to these regressors. First of all, our regulatory variable (*REG2014*) now seems to gain some significance and, although weak, an expected positive sign. On the other hand, when we try to address its moderation effect on the EI impact of design investments, *YOUNG* turns out to be weakly significant *per se*, and with a negative sign, pointing to an experience advantage of older firms in the eco-innovation realm, which has recently be identified by other studies (see Leoncini et al., 2017). With respect to the interaction terms, as it was previously discussed, only *YOUNG* moderates the effect of *DESIGN_inv* on *EI*.

In concluding our analysis, in a sort of robustness check, it could be interesting to consider whether the results we have obtained remain unchanged when a more specific kinds of EI is addressed, for which the effect of design could be more directed and thus less confounded by other mechanisms. In order to do that, we have re-run our bivariate probit on a different specification of EI, which excludes those firms, among the adopters of sustainable technologies, having declared only process and not product innovations. While an indirect way to address it, this procedure would enable us to get closer to the role of design for new product development.

Quite interestingly, our previous results appear in general robust (Table 6).

Insert Table 6 around here

The main exception is actually represented by the loss of significance of RD and of the moderation effect of *YOUNG*, and, on the other hand, by the increasing role of REG2014, which turns to be mostly significant. As for our main research question, the role of DESIGN with respect to the eco-impact of design investments seems to emerge also when design is used in planning and devising the productions processes in which sustainable technologies could be applied.

5. Conclusions

"Eco-design" is more than the simple "integration" of an environmental concern in product development and/or process planning. The issue is not just that of identifying the proper technique and procedure to make this integration happen and/or to devise suitable policy schemes (e.g. eco-design regulations) to make firms internalise the externalities of eco-design. Taking a wider perspective than that actually prevailing in environmental economics, and combining eclectically recent research streams on eco-innovation and on the economics and management of intangibles, "eco-design" can be looked in a less "blax-boxed" way and "un-packed" as a relationship between: on the one hand, the environmental performance firms reach through their innovations – i.e. eco-innovation; on the other hand, the economic and organisational choices they make with respect to an important intangible asset like design.

In this paper we have addressed this relationship, with respect to which we have put forward positive expectations. Even when they are not explicitly targeted to the development of formal eco-design practices, design investments could help firms discover new technological opportunities and solutions with a favourable environmental impact. Furthermore, a positive relationship between environmental performances and design can be helped by using design as a pivotal business activity and by giving it a core role within the organisation of the firm.

Using the potential of the Eurobarometer 2015 survey, we have been able to submit these expectations to a first but wide and systematic empirical test. By referring to more than 2700 European and non-European firms in the period 2012-2014, we have actually made an important step ahead with respect to the dominant use of case-study evidence in the analysis of eco-design.

Overall, the results we have obtained are supportive of the actual existence of eco-design as relationship, rather than as a practice, that is, of a positive relationship between design and eco-innovation. Investing in design is actually associated with a greater capacity of eco-innovating, apparently more than for other standard eco-innovation drivers. These investments also depend on the way design is used within the firm, which thus also matters for eco-design. Finally, the effect of design for eco-innovation is positively moderated by the investing firm being young rather than old, suggesting this status could entail more degrees of freedom in making a new and alternative (i.e. sustainable) use of design.

From an academic point of view, these results contribute to two streams of literature, in addition to that on eco-design in environmental economics. First of all, we add to the growing research on the determinants and drivers of eco-innovation, in which design has so far found attention mainly in theoretical terms (see, for example, Carrillo et al., 2009), with respect to more specific geographical contexts and indistinguishably from other non-R&D activities (see, for example, Marzucchi and Montresor, 2017). Second, we also add to the still "thin" literature on the "soft-side of eco-design" (Boks, 2006), in which the use and role of design within the firm has been so far only marginally addressed and mainly through dedicated case-studies (see, for example, Johansson and Magnusson, 2006; Tingström et al. 2006).

These results have also important strategic and policy implications. In strategic terms, the successful implementation of eco-design, meant as an innovative and environmentally sustainable use and impact of design, requires firms to equip with design competencies and design-oriented business models and organisational structures. The amount of resources firms decide to invest in design, and not only in the development/adoption of specific eco-design techniques, becomes a crucial eco-design aspect. In the same respect, the use firms make of design in general within the firm, that is, in terms of centrality in the design ladder model, reveals as much important for its effective eco-use.

From a policy point of view, the current spectrum of eco-design interventions appears also too limited. On the one hand, their fields of application seem to require an extension with respect to specific realms in which it has so far concentrated, at least in Europe (e.g. eco-labelling and energy-labelling). On the other hand, while making firms aware of the opportunities to extend the environmental dimension to integrate in design - for example, through its circular-economy consistent use - policies should in parallel help firms build up incentives to invest and management intangibles, like design, in a strategic way.

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Tables and Figures

Table 1: Main variables definition and descriptive statistics

	Variable	**Description**	N	Mean	SD	Min	Max
0	EI	D equals one if the company has adopted or plans to adopt in the next year sustainable manufacturing technologies	2788	0.43	0.50	0	1
1	DESIGN_inv_0	D equals one if design investment is 0% of company's turnover	2788	0.29	0.45	0	1
2	DESIGN_inv<1	D equals one if design investment is <1% of company's turnover	2788	0.173	0.378	0	1
3	DESIGN_inv1-5%	D equals one if design investment is between 1% and 5% of company's turnover	2788	0.348	0.477	0	1
4	DESIGN_inv>5%	D equals one if design investment is >5% of company's turnover	2788	0.191	0.393	0	1
5	DESIGN_inv	D equals one if Design of products and services has a positive share (> 0%) of company' turnover investments	2788	0.54	0.50	0	1
6	DESIGN_NOT_USED	D equals one if design is not used in the company	2788	0.22	0.42	0	1
7	DESIGN_NOT_SYST	D equals one when the company does not work systematically on design	2788	0.15	0.36	0	1
8	DESIGN_AESTHETIC	D equals one when design is used as last finish to enhance appearance and attractiveness of the final product	2788	0.16	0.37	0	1
9	DESIGN_INTEGRAL	D equals one when design is an integral component in the company's strategy	2788	0.28	0.45	0	1
10	DESIGN_CENTRAL	D equals one when design is a central element in the company's strategy	2788	0.19	0.39	0	1
11	RD	D equals one if R&D has a positive share (> 0%) of company' turnover investments	2788	0.63	0.48	0	1
12	LSIZE	Log in the number of employees	2788	3.57	1.64	0	9.16
13	YOUNG	D equals one if the company is young, i.e. if it was founded after January 2014	2788	0.06	0.24	0	1
14	REG2014	Total environmental protection expenditure by countries-sectors (source Eurostat: env_ac_epneec)	2788	6.76	18.16	0	286.2
15	MKT_TESTING	Market testing of a product or service before launch, as an effective public support for commercialization of innovative goods or services	2788	0.13	0.34	0	1
16	GROUP	D equals one if the company belongs to a group	2788	0.33	0.47	0	1
17	HIGHINNO	D equals one when the company invested in innovation activities more than 11% of its turnover	2788	0.08	0.28	0	1
18	TURN GROWTH > 25%	D equals one when the company reports a growth in turnover greater than 25% with respect to 2012	2788	0.10	0.30	0	1
19	TURN GROWTH 5% to 25%	D equals one when the company reports a growth in turnover greater between 5% and 25% with respect to 2012	2788	0.35	0.48	0	1
20	TURN UNCHANGED	D equals one when the company reports an unchanged turnover with respect to 2012	2788	0.36	0.48	0	1
21	TURN LOST 5% to 25%	D equals one when the company reports a loss in turnover between 5% and 25% with respect to 2012	2788	0.15	0.36	0	1
22	TURN LOST > 25%	D equals one when the company reports a loss in turnover greater than 25% with respect to 2012	2788	0.04	0.21	0	1
23	INTERNATIONAL_sales	Percentage of turnover from sales in EU or other countries	2788	34.59	37.04	0	100
24	WEAK_DISTR	D equals one in the presence of weak distribution channels that hamper the commercialization of innovative goods or services	2788	0.41	0.49	0	1

Table 2: Spearman correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1																							
2	-0.29	1																						
3	-0.47	-0.33	1																					
4	-0.31	-0.22	-0.36	1																				
5	-0.69	-0.49	0.68	0.45	1																			
6	0.30	-0.08	-0.12	-0.13	-0.21	1																		
7	0.09	0.06	-0.06	-0.08	-0.13	-0.22	1																	
8	-0.10	0.07	0.05	-0.01	0.04	-0.24	-0.19	1																
9	-0.15	-0.02	0.12	0.05	0.15	-0.33	-0.26	-0.27	1															
10	-0.14	-0.01	0.00	0.16	0.13	-0.26	-0.20	-0.21	-0.30	1														
11	-0.34	0.07	0.12	0.19	0.26	-0.19	0.00	0.06	0.08	0.05	1													
12	-0.08	0.09	0.05	-0.05	0.01	-0.11	0.03	0.05	0.06	-0.02	0.22	1												
13	-0.02	0.01	-0.02	0.03	0.01	0.00	0.03	-0.02	0.02	-0.04	-0.04	-0.11	1											
14	-0.02	0.06	0.01	-0.05	-0.03	0.02	0.04	0.04	0.01	-0.11	0.10	0.03	-0.04	1										
15	-0.11	-0.01	0.02	0.11	0.10	-0.09	-0.03	0.03	0.01	0.08	0.13	0.06	0.02	0.02	1									
16	-0.09	0.05	0.01	0.04	0.05	-0.08	0.02	-0.01	-0.01	0.09	0.16	0.45	0.00	0.05	0.07	1								
17	-0.07	-0.06	-0.05	0.20	0.11	-0.02	-0.02	0.00	0.01	0.03	0.06	-0.07	0.04	-0.06	0.05	-0.01	1							
18	-0.01	0.04	-0.05	0.03	-0.02	-0.03	0.02	-0.01	-0.02	0.04	0.06	0.01	0.15	-0.03	0.03	0.03	0.08	1						
19	-0.07	0.02	0.01	0.06	0.05	-0.04	0.03	-0.01	0.02	0.00	0.09	0.08	-0.03	0.01	-0.03	0.07	-0.01	-0.24	1					
20	0.07	-0.02	-0.01	-0.05	-0.05	0.06	-0.01	0.01	-0.02	-0.04	-0.05	-0.03	-0.06	0.04	0.01	-0.04	-0.03	-0.25	-0.55	1				
21	-0.01	-0.03	0.04	-0.01	0.03	0.00	-0.03	0.00	0.01	0.01	-0.06	-0.01	0.00	-0.01	0.04	-0.01	0.00	-0.14	-0.31	-0.32	1			
22	0.03	0.00	0.00	-0.04	-0.03	-0.02	-0.03	0.01	0.01	0.02	-0.07	-0.12	-0.02	-0.05	-0.04	-0.09	-0.01	-0.07	-0.16	-0.16	-0.09	1		
23	-0.09	0.03	0.02	0.05	0.06	-0.05	0.02	0.01	0.04	-0.02	0.19	0.46	-0.07	-0.04	0.07	0.31	0.03	0.10	0.09	-0.03	-0.10	-0.10	1	
24	-0.09	0.03	0.05	0.01	0.06	-0.09	-0.06	0.04	0.05	0.05	0.06	0.02	0.07	0.02	0.08	-0.04	0.01	-0.03	-0.06	0.00	0.07	0.05	-0.03	1

Table 3: The effects of design on eco-innovation: Probit estimation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DESIGN_inv	0.2898***	0.2892***	0.2897***	0.2777***	0.2449***	0.2401***	0.4841***
	(0.0519)	(0.0519)	(0.0519)	(0.0522)	(0.0540)	(0.0536)	(0.1260)
LSIZE	0.1293***	0.1236***	0.1138***	0.1196***	0.1209***	0.1195***	0.1514***
	(0.0167)	(0.0182)	(0.0197)	(0.0199)	(0.0201)	(0.0200)	(0.0266)
RD	0.1577***	0.1539***	0.1526***	0.1423**	0.1321**	0.1423**	0.1398**
	(0.0571)	(0.0572)	(0.0573)	(0.0576)	(0.0582)	(0.0577)	(0.0576)
REG2014	0.0027	0.0026	0.0027	0.0027	0.0029*	0.0026	0.0028*
	(0.0017)	(0.0017)	(0.0017)	(0.0017)	(0.0017)	(0.0017)	(0.0017)
YOUNG	0.0864	0.0872	0.0758	0.0643	0.0862	-0.3097*	0.0608
	(0.1036)	(0.1037)	(0.1038)	(0.1033)	(0.1042)	(0.1707)	(0.1035)
INTERNATIONAL_sales		0.0007	0.0005	0.0004	0.0005	0.0005	0.0004
		(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0008)
GROUP			0.0846	0.0807	0.0622	0.0764	0.0801
			(0.0625)	(0.0625)	(0.0629)	(0.0625)	(0.0625)
HIGHINNO				0.2559***	0.2428***	0.2580***	0.2496***
				(0.0889)	(0.0896)	(0.0895)	(0.0892)
DESIGN_NOT_SYST					0.0558		
					(0.0837)		
DESIGN_AESTHETIC					0.1005		
					(0.0840)		
DESIGN_INTEGRAL					0.0820		
					(0.0739)		
DESIGN_CENTRAL					0.3330***		
					(0.0841)		
YOUNG#DESIGN_inv						0.6408***	
						(0.2200)	
DESIGN_inv#Lsize							-0.0566*
							(0.0313)
Constant	-1.1674***	-1.1742***	-1.1533***	-1.2007***	-1.2805***	-1.1853***	-1.3143***
	(0.1482)	(0.1484)	(0.1489)	(0.1499)	(0.1544)	(0.1508)	(0.1605)
N	2788	2788	2788	2788	2788	2788	2788
pseudo R^2	0.0563	0.0564	0.0569	0.0590	0.0637	0.0614	0.0599

*Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, 27 country dummies and 7 sector dummies are included and not reported. The 7 sector dummies are the following: CA, CB, CC, CD-CG, CH, CI-CL, CM (Nace Rev 2)*

Table 4: The effects of design on eco-innovation, Probit estimation: estimated marginal effects for column 1 to 5

	(1)	(2)	(3)	(4)	(5)
DESIGN_inv	0.1069***	0.1066***	0.1067***	0.1020***	0.0895***
LSIZE	0.0477***	0.0456***	0.0419***	0.0440***	0.0442***
RD	0.0583***	0.0569***	0.0564***	0.0524**	0.0484**
REG2014	0.0010	0.0010	0.0010	0.0010	0.0010*
YOUNG	0.0320	0.0323	0.0281	0.0237	0.0317
INTERNATIONAL_sales		0.0002	0.0002	0.0002	0.0002
GROUP			0.0314	0.0299	0.0228
HIGHINNO				0.0953***	0.0898***
DESIGN_NOT_SYST					0.0204
DESIGN_AESTHETIC					0.0367
DESIGN_INTEGRAL					0.0300
DESIGN_CENTRAL					0.1217***
N	2788	2788	2788	2788	2788

(1) Average marginal effects (dy/dx) of all covariates on the discrete change of EI from 0 to 1 are reported. Note: dy/dx for dichotomous variables is the discrete change from the base level 0.

(2) To provide interpretable effect on the interaction variables YOUNG#DESIGN_inv and Lsize#DESIGN_inv as of column (6) and column (7) of the former Table 6, those are reported via visual representation in the next Figure 1 and Figure 2.

Figure 1: Marginal effects for the interaction term YOUNG and DESIGN_inv

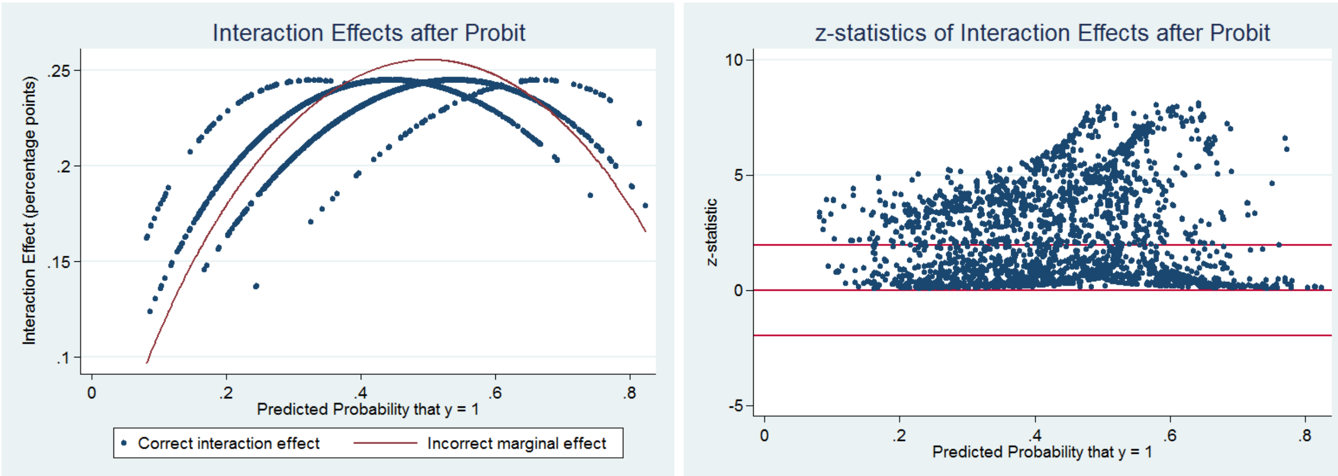

Figure 1: Marginal effects for the interaction term Lsize and DESIGN_inv

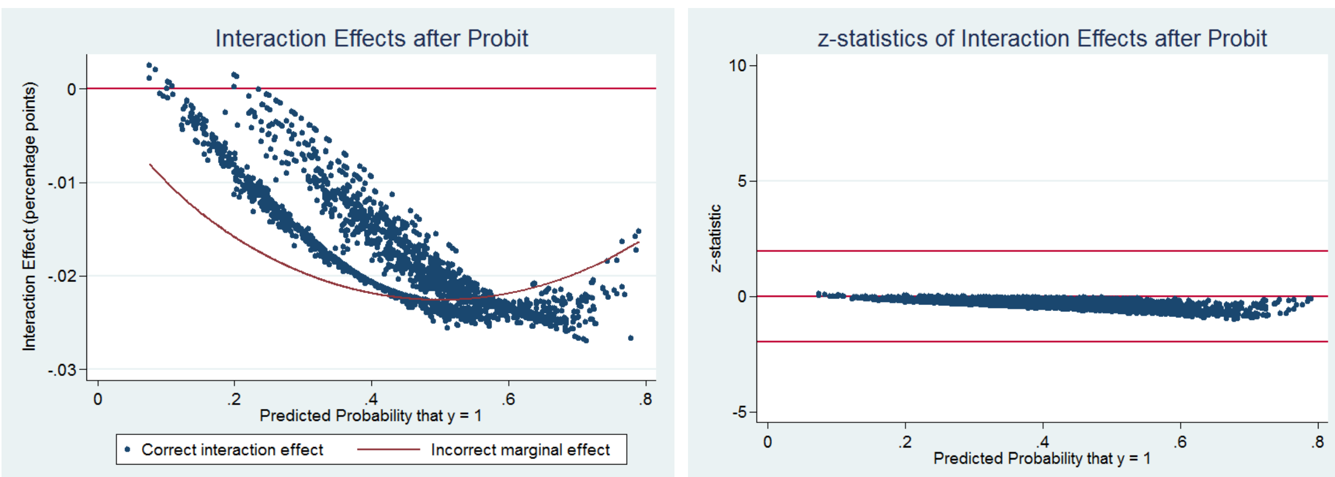

Table 5: The effects of design on eco-innovation: Bivariate probit estimation results

Step 2: EI equation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DESIGN_inv	0.8640***	0.8629***	0.8505***	0.8234***	0.7822***	1.0299***	0.8268***	0.9969***	0.8727***
	(0.2094)	(0.1743)	(0.1958)	(0.2027)	(0.1959)	(0.2695)	(0.1889)	(0.2170)	(0.1667)
LSIZE	0.1215***	0.1161***	0.1076***	0.1134***	0.1133***	0.1445***	0.1132***	0.1071***	0.1100***
	(0.0184)	(0.0180)	(0.0190)	(0.0209)	(0.0190)	(0.0304)	(0.0189)	(0.0196)	(0.0188)
RD	0.1287**	0.1251**	0.1248**	0.1160**	0.1165**	0.1135*	0.1161**	0.1026*	0.1108**
	(0.0639)	(0.0496)	(0.0575)	(0.0553)	(0.0474)	(0.0594)	(0.0544)	(0.0575)	(0.0501)
YOUNG	0.0793	0.0799	0.0702	0.0597	-0.2977*	0.0559	0.0592	0.0620	0.0720
	(0.0878)	(0.1025)	(0.1045)	(0.1038)	(0.1809)	(0.1282)	(0.1131)	(0.1026)	(0.1007)
REG2014	0.0027**	0.0026	0.0027	0.0027	0.0026	0.0028	0.0027	0.0026	0.0028*
	(0.0012)	(0.0019)	(0.0018)	(0.0018)	(0.0016)	(0.0019)	(0.0017)	(0.0019)	(0.0015)
INTERNATIONAL_sales		0.0006	0.0005	0.0004	0.0005	0.0004	0.0002	0.0002	0.0003
		(0.0007)	(0.0009)	(0.0009)	(0.0008)	(0.0007)	(0.0007)	(0.0008)	(0.0008)
GROUP			0.0753	0.0721	0.0681	0.0712	0.0725	0.0679	0.0709
			(0.0695)	(0.0567)	(0.0649)	(0.0742)	(0.0663)	(0.0566)	(0.0621)
HIGHINNO				0.2398**	0.2419***	0.2334**	0.1412*	0.0981	0.1283
				(0.0943)	(0.0882)	(0.0991)	(0.0744)	(0.0932)	(0.0871)
YOUNG#DESIGN_inv					0.6113***				
					(0.2143)				
DESIGN_inv#Lsize						-0.0556			
						(0.0342)			
Constant	-1.3845***	-1.3907***	-1.3685***	-1.4076***	-1.3919***	-1.5205***	-1.3826***	-1.4152***	-1.3863***
	(0.1463)	(0.1532)	(0.1569)	(0.1700)	(0.1720)	(0.1516)	(0.1441)	(0.1546)	(0.1610)

Step 1: Design investment equation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DESIGN_NOT_USED	-0.6561*** (0.0608)	-0.6563*** (0.0681)	-0.6570*** (0.0713)	-0.6573*** (0.0806)	-0.6582*** (0.0591)	-0.6576*** (0.0694)	-0.6463*** (0.0770)	-0.6105*** (0.0677)	
MKT_TESTING	0.3569*** (0.0716)	0.3564*** (0.0850)	0.3558*** (0.0730)	0.3553*** (0.0935)	0.3533*** (0.0711)	0.3556*** (0.0753)	0.3430*** (0.0756)	0.3255*** (0.0815)	0.2991*** (0.0841)
INTERNATIONAL_sales							0.0012 (0.0007)	0.0013* (0.0006)	0.0012* (0.0007)
HIGHINNO							0.5123*** (0.0828)	0.5213*** (0.1054)	0.5111*** (0.1130)
TURN GROWTH > 25%								-0.1823** (0.0906)	-0.1807** (0.0823)
TURN GROWTH 5% to 25%								0.1286** (0.0545)	0.1284* (0.0668)
TURN LOST 5% to 25%								0.0709 (0.0707)	0.0644 (0.0960)
TURN LOST > 25%								-0.1670 (0.1406)	-0.1760 (0.1315)
WEAK_DISTR								0.1609** (0.0642)	0.1175** (0.0557)
DESIGN_NOT_SYST									0.1055 (0.0809)
DESIGN_AESTHETIC									0.6370*** (0.0822)
DESIGN_INTEGRAL									0.8207*** (0.0870)
DESIGN_CENTRAL									0.8388*** (0.0801)
Constant	0.1106 (0.1551)	0.1107 (0.1529)	0.1109 (0.1539)	0.1120 (0.1374)	0.1116 (0.1525)	0.1120 (0.1453)	-0.0159 (0.1367)	-0.1005 (0.1399)	-0.6981*** (0.1515)

(**CONT'D**)

Rho	-0.3968**	-0.3964***	-0.3862**	-0.3739**	-0.3697**	-0.3767**	-0.3752**	-0.5192***	-0.4274***
	(0.1629)	(0.1358)	(0.1584)	(0.1765)	(0.1506)	(0.1692)	(0.1529)	(0.1825)	(0.1380)
N	2788	2788	2788	2788	2788	2788	2788	2788	2788
Average marginal effect of DESIGN_inv on EI	0.0962	0.0959	0.0963	0.0921	0.0922	0.0920	0.0918	0.0858	0.0794
Wald test of rho=0 Chi_2	7.059	7.064	6.847	6.468	6.293	6.577	6.362	12.63	12.78
Wald test of rho=0 p> Chi_2	0.008	0.008	0.009	0.011	0.012	0.010	0.012	0.000	0.000
Murphy's score test for biprobit Chi_2	23.63	23.87	25.18	21.42	19.10	19.49	20.04	22.20	28.79
Murphy's score test for biprobit p> Chi_2	0.005	0.005	0.003	0.011	0.024	0.021	0.018	0.009	0.001

*Standard errors in parentheses * p < 0.10, ** p < 0.05, *** p < 0.01, 27 country dummies and 7 sector dummies are included and not reported.*

The 7 sector dummies are the following: CA, CB, CC, CD-CG, CH, CI-CL, CM (Nace Rev 2)

Table 6: The effects of design on eco-innovation: Bivariate probit estimation results, excluding firms being process but not product innovators

Step 2: EI equation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DESIGN_inv	0.9937*** (0.1986)	0.9936*** (0.2379)	0.9920*** (0.2510)	0.9661*** (0.2374)	0.9272*** (0.2343)	1.1543*** (0.2050)	0.9737*** (0.2063)	1.2851*** (0.2026)	1.0861*** (0.1888)
LSIZE	0.1377*** (0.0262)	0.1372*** (0.0253)	0.1253*** (0.0244)	0.1300*** (0.0217)	0.1322*** (0.0295)	0.1618*** (0.0308)	0.1296*** (0.0273)	0.1154*** (0.0287)	0.1217*** (0.0276)
RD	0.1016 (0.0760)	0.1012 (0.0722)	0.0992 (0.0620)	0.0913 (0.0663)	0.0917 (0.0779)	0.0883 (0.0728)	0.0910 (0.0814)	0.0651 (0.0698)	0.0769 (0.0766)
YOUNG	-0.0576 (0.1638)	-0.0577 (0.1361)	-0.0737 (0.1424)	-0.0734 (0.1623)	-0.3571 (0.2386)	-0.0814 (0.1349)	-0.0749 (0.1221)	-0.0672 (0.1480)	-0.0805 (0.0894)
REG2014	0.0049** (0.0024)	0.0049** (0.0023)	0.0049 (0.0030)	0.0049* (0.0026)	0.0050** (0.0023)	0.0049** (0.0021)	0.0049*** (0.0016)	0.0047** (0.0019)	0.0052** (0.0025)
INTERNATIONAL_sales		0.0001 (0.0009)	-0.0000 (0.0011)	-0.0001 (0.0011)	-0.0001 (0.0010)	-0.0001 (0.0011)	-0.0006 (0.0013)	-0.0008 (0.0010)	-0.0006 (0.0012)
GROUP			0.1000 (0.0851)	0.0892 (0.0823)	0.0850 (0.1009)	0.0851 (0.0696)	0.0899 (0.0875)	0.0940 (0.0700)	0.0968 (0.0845)
HIGHINNO				0.2106** (0.1058)	0.2138* (0.1169)	0.2025* (0.1194)	0.1101 (0.0983)	0.0254 (0.1282)	0.0807 (0.1248)
YOUNG#DESIGN_inv					0.4883 (0.3039)				
DESIGN_inv#c.Lsize						-0.0533 (0.0423)			
Constant	-1.4992*** (0.1918)	-1.4993*** (0.2111)	-1.4742*** (0.1566)	-1.5088*** (0.1748)	-1.5055*** (0.2019)	-1.6182*** (0.1939)	-1.4768*** (0.2006)	-1.5030*** (0.1918)	-1.4819*** (0.1969)

Step 1: Design investment equation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DESIGN_NOT_USED	-0.7864*** (0.0815)	-0.7864*** (0.0975)	-0.7869*** (0.0888)	-0.7866*** (0.0822)	-0.7870*** (0.0787)	-0.7870*** (0.0845)	-0.7672*** (0.0931)	-0.6824*** (0.0787)	
MKT_TESTING	0.3039*** (0.0961)	0.3038*** (0.0813)	0.3038*** (0.1034)	0.3037*** (0.0905)	0.3029*** (0.1101)	0.3044*** (0.0902)	0.2819*** (0.0917)	0.2479** (0.0994)	0.2502** (0.1040)
INTERNATIONAL_sales							0.0026*** (0.0009)	0.0027*** (0.0008)	0.0024** (0.0011)
HIGHINNO							0.5283*** (0.1311)	0.5294*** (0.1233)	0.5071*** (0.1561)
TURN GROWTH > 25%								-0.2309** (0.1117)	-0.1953 (0.1509)
TURN GROWTH 5% to 25%								0.0746 (0.0619)	0.0916 (0.0752)
TURN LOST 5% to 25%								-0.0644 (0.1032)	-0.0508 (0.1275)
TURN LOST > 25%								-0.1436 (0.1381)	-0.1569 (0.1375)
WEAK_DISTR								0.3539*** (0.0763)	0.3106*** (0.0886)
DESIGN_NOT_SYST									0.1466 (0.1139)
DESIGN_AESTHETIC									0.6758*** (0.1072)
DESIGN_INTEGRAL									0.9280*** (0.1242)
DESIGN_CENTRAL									0.8761*** (0.1026)
Constant	0.0361 (0.2035)	0.0361 (0.1440)	0.0358 (0.1425)	0.0358 (0.1337)	0.0354 (0.1962)	0.0359 (0.1542)	-0.1375 (0.2035)	-0.3287* (0.1899)	-1.0015*** (0.2053)

(**CONT'D**)

Rho	-0.3952**	-0.3953*	-0.3926*	-0.3801**	-0.3727	-0.3802**	-0.3841**	-0.6880***	-0.5006***
	(0.1570)	(0.2021)	(0.2143)	(0.1845)	(2.0302)	(0.1666)	(0.1563)	(0.2082)	(0.1802)
N	1709	1709	1709	1709	1709	1709	1709	1709	1709
Average marginal effect of DESIGN_inv on EI	0.141	0.141	0.142	0.138	0.138	0.137	0.138	0.122	0.119
Wald test of rho=0 Chi_2	5.393	5.395	5.425	5.089	4.876	5.104	4.955	15.85	12.12
Wald test of rho=0 p>Chi_2	0.020	0.020	0.019	0.024	0.027	0.024	0.026	0.000	0.000
Murphy's score test for biprobit Chi_2	18.68	18.66	19.74	16.42	12.32	14.69	18.26	23.30	27.40
Murphy's score test for biprobit p>Chi_2	0.028	0.028	0.019	0.058	0.196	0.099	0.032	0.005	0.001

*Standard errors in parentheses * p < 0.10, ** p < 0.05, *** p < 0.01, 27 country dummies and 7 sector dummies are included and not reported. The 7 sector dummies are the following: CA, CB, CC, CD-CG, CH, CI-CL, CM (Nace Rev 2)*