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Unfolding heterogeneity:

the *different* policy drivers of *different* eco-innovation modes

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Abstract
The present paper investigates whether and to what extent firms pursuing different approaches to environmental innovation differently "score" on policy measures. The analysis shows that distinct "modes" of eco-innovating are related to distinct institutional drivers, among environmental and innovation policies. The study directly keys into the debate in the literature about to effectiveness of distinct public policies in spurring EI by providing an enriched and more nuanced view of environmental innovation processes, with important implications for theorizing about policies aiming at fostering the transition towards increased sustainability.

Keywords: *Environmental Innovation, Environmental Policies, Innovation Policies, Innovation Modes, Cluster analysis*

1. Introduction

The key role of public actions for sustaining pollution reduction while encouraging the development and adoption of environmentally beneficial technology is justified by the presence of market failures, that might be responsible for the suboptimal supply of both environmental protection and green innovations (Jaffe et al., 2005).

Within this framework, a broad research effort has been devoted to understand whether and to what extent public policies success in providing incentives for the adoption of better abatement technologies. Most of it confirms the relevance of both environmental (Aghion et al., 2016;

Brunnermeier and Cohen, 2003; Calel and Dechezlepretre, 2016; Jaffe and Palmer, 1997; Popp, 2006; Triguero et al., 2015) and innovation policies (Costantini et al., 2015; 2017; Horbach 2012; 2016; Ghisetti; 2018) in fostering the pace of introduction and diffusion of environmental technologies.

These contributions make use of a broad definition of environmental innovation (here-after EI) or, at best, identify EI row classes (as for example *efficiency-improving vs pollution-reducing, product vs process* or *end-of-pipe technologies vs cleaner production technologies*) to scrutinize the impact of distinct institutional drivers in sustaining EI engagement.

However, a step forward in the identification of EI's features has been recently made by a recent stream of literature. This new approach claims that environmental objectives, representing the starting point of EI processes (Jakobsen and Clausen, 2016; OECD, 2005, Paulraj, 2009;), might be achieved through several technological trajectories (Castellacci and Lee, 2018) and distinct combinations among forms of knowledge (Marzucchi and Montresor, 2017). Accordingly, as environmental goals are strictly linked to policy drivers and distinct policies may induce to different EI behaviors (Marin et al., 2015), here it is argued that investigating the relations between environmental objectives and policy determinants is of paramount importance for launching accurate policy actions on EI activities.

In order to provide a contribution in this direction, the present paper bridges together these two research lines and investigates the policy determinants of distinct patters of environmental innovation, here-after "EI modes". In particular, our research question investigates whether and to what extent policy drivers are different with respect to firms with distinct EI modes.
To assess this issue, after reviewing both environmental and innovation policy drivers of EI and their potential links with different environmental strategies, a large-scale survey data provided by the Italian Community Innovation Survey is exploited in order to examine to what extent firms pursuing different approaches to environmental innovation differently "score" on policy measures.

This study contributes to the literature in two ways. The first contribution consists of the framework of innovation modes which, in the vein of the evolutionary theory (Nelson and Winter, 2009, Nelson, 1991¸ Tether and Tajar, 2008), provides evidence that firms pursue several approaches to EI. A related contribution is that this research directly keys into the debate in the literature about to effectiveness of distinct public policies in spurring EI, with the added insight of recognizing the role of distinct policy tools in shaping several EI dynamics. Thus, an enriched and more nuanced view of EI processes is here provided, with important implications for theorizing about policies aiming at fostering the transition towards increased sustainability.

The remainder of this chapter is organized as follows. Section 2 provides a synthetic but extensive survey on the institutional determinants of EI while Section 3 discusses the research questions. Section 4 presents the data, the empirical application and illustrates the results. Finally, Section 5 concludes by discussing the main findings.

2. The role of public policies

The key role of public policies in managing sustainable transition has been emphasized by a large number of empirical studies devoted at investigating the potential role of public policies in supporting the introduction and diffusion of new environmental technologies (Del Río, 2009; Foxon, 2013; Horbach, 2008; Mowery et al., 2010; Newell, 2010, OECD, 2005, 2010; Triguero et al., 2013). Among the several classifications proposed by scholars (e.g., Crespi and Quatraro, 2013, Crespi et al, 2015; Del Río et al., 2010; Kemp, 1997; Rennings, 2000; Wieczorek and Hekkert, 2012), policy tools may be grouped into two pillars belonging to environmental and innovation policy domain, respectively (see Crespi 2016 for a detailed list).

Command and control vs price-based policy instruments

The first category refers to environmental policies, that consist of regulation/command instruments (CACs) and price-based tools (MBIs).

The CAC's group includes measures imposed by institutions, as for example a performance standard to be met or a technology to be adopted, as well as a certificate or registry over harmful substances to be used. MBI tools encompass environmental taxes and cap and trade systems. The former aim at directly internalizing in the producers the external costs of pollutant activities that are spread over the society in terms of environmental damage by taking different forms, as taxes on energy, SO2 and NOx emissions or taxes on inputs of production processes (water, fuel, use of pesticides) or outputs (air tickets). On the contrary, the latter impose an upper threshold for selected pollutants (cap) after that permits to pollute are allocated and traded (trade) in order to achieve a cost-effective way to reduce emissions.

Both CACs and MIBs present pros and cons. When compared to decentralized incentive systems, such as MIBs, *standards-based* policies are considered less dynamically efficient as the imposition of a standard does not provide enough long-term innovative incentives to develop alternative and better technologies. Otherwise, technology standards may increase the risk of getting stuck into technological "lock-in" since these instruments tend to basically promote the adoption of the less costly technology available when the regulation is established (Kemp, 2000). For all these reasons, CAC instruments may discourage the exploration of radical, and much costly, innovation activities in favor of more incremental and less effective solutions as, for example, *end-of-pipe* technologies. So that, CACs may reduce the potential positive impact of innovation in terms of broader and more ambitious environmental goals (Frondel et al. 2008, 2010; Jaffe et al., 2002;).

On the contrary, the incentives provided by MIBs policies may be more persistent than those associated with CACs, as the former do not vanish when the goal has been met. In this view, MBIs may guarantee a constant demand for innovation (Stewart, 1981). Therefore, in providing a stimulus for going beyond environmental standards, MBIs may create incentive for the exploration of non-incremental innovation (Popp, 2006), thus accelerating the pace of radical innovations and enabling the development of *cost-efficient* environmental technologies (Crespi et al. 2015, Crespi, 2016).

However, the superiority of MBI's on CACs is not conclusive for, at least, two reasons. First, the effectiveness of economic instruments in stimulating EI strictly relies on firms' responsiveness to price signals which, in turn, may induce firms to lose incentive in introducing green technologies when the cost of polluting is not sufficiently high. Second, if established unliterally in sectors characterized by huge environmental costs and sheltered from international competitiveness, MBI systems risk generating serious competitive disadvantages when compared to countries whit less strict regulations.

Regarding the pros of technology-forcing standard, CACs may overperform MBIs in boosting the diffusion speed of environmental technologies by means of two channels. First, when a technological standard is adopted by a country, exporting countries are consequently forced to adapt their processes and products to the new requirement. Second, adopting countries are also in the condition to penetrate markets where environmental standards have been already established.

In this framework, the relationship between environmental policies and EI is still debated in the discussion on how translate the demand for a greener environment by designing effective policies. For instance, Rennings (1998) claims that environmental regulation is the most cost-efficient way of spurring EI, while Porter and van der Linde (1995) and Kammerer (2009) point the emphasis on the pivotal role played by regulation-inducing EI in providing adopters with competitive advantages as, according to this view, regulation is expected to change both level and nature of competition between companies. Kemp and Andersen (2004) look at regulation as a way to shape EI instead of start or stop it, while Khanna et al. (2009) and Maxwell et al. (2000) argue that only when anticipated, environmental policies provide sufficient stimuli for EI. In emphasizing the role of the policy quality, Costantini and Mazzanti (2012) sustain that only if "properly designed" environmental regulation can promote the development of green technologies instead of harming firms' productivity and competitiveness (Brock and Taylor 2005) through higher production costs (Hicks, 1932).

From the empirical point of view, the early studies investigating the link between public policies and innovation have largely made use of the notion of environmental pressures. In specific, pollution abatement and control expenditures (PACE) have been often adopted as environmental policy indicators. For instance, the pioneering econometric study by Jaffe and Palmer (1997) carried out on US manufacturing sectors during the period 1973-1991 shows that environmental regulation stringency, proxied by PACE, positively affects R&D expenditures but not patenting activities. Post-sequential studies using similar analytical frameworks, confirm the potential positive effect of environmental regulation on innovation for US (Brunnermeier and Cohen, 2003), Taiwan (Yang et al., 2012) and Canada (Patry and Lajeunesse, 2008).

With a more narrowed perspective, other analysis focusing on distinct environmental policy instruments argue that superior technological responses to environmental pressures may be induced by both standard and economic incentives. Popp (2006) finds that MBIs are more effective than CACs in stimulating patenting activities in Germany, US and Japan. Similar evidences emerge in Triguero et al., (2015), where EI's determinants are scrutinized for 5,135 SME located in 27 European to scrutinize EI's determinants. The analysis shows that MBIs (measured as environmental taxation) are key factors in explaining the adoption of cleaner technologies, especially when firms are medium sized. In the same vein, Aghion et al. (2016) claim that tax-inclusive fuel prices induce clean technologies innovations, while Calel and Dechezlepretre (2016) find that the involvement in MBI programs (namely the European Union Emission Trading System) increases firms' probability of engaging in low-carbon patent activities by 10%, without crowding-out effects on other technologies.

Different findings have been provided by a bulk of empirical evidences where CACs have been found to overperform MBIs in boosting firms' environmental-friendly behaviors. For instance, exploiting 2003 firm-level data for 7 OECD countries, Frondel et al. (2008) point out that CACs are more important in promoting not-incremental innovation (*end-of-pipe* technologies) than more radical one (cleaner production technologies), while MBIs appear to be ineffective for both *end-of-pipe* and cleaner technologies. The positive link between CACs and *end-of-pipe* technologies is also found by Demirel and Kesidou (2011), who confirm the ineffectiveness of MBIs (measured as environmental taxation) in sustaining more radical EI activities, such as cleaner production technologies and environmental R&D investments.

The role of supply-push and demand-pull instruments

Policy tools can also be divided in *supply-push* and *demand-pull* instruments. The former concern subsidies in the form of grants, tax reduction and soft or interest-free loans, while the latter essentially refer to green purchasing by governments. According to the classical view of public intervention, the use of these instruments deals with the correction of innovation-related market failures, such as (i) uncomplete appropriability, (ii) financial barriers and (iii) uncertain demand. In this context, innovation policies are expected to provide private agents with incentives to raise the investments' level up to the socially optimal equilibrium (Arrow, 1962).

In general, the first two failures call for *supply-push* policies. On the one hand, technological spillovers stemming from innovative investments do not guarantee the complete appropriability of innovation outcomes, because the imitation might be too easy or the probability that other may benefit from the innovation is too high. On the other hand, the highly risky and uncertain nature of innovation discourages external investors from financing R&D projects. Both these failures generate an under-investment in innovative activities, especially when firms are small and belong to high-tech firms (Canepa and Stoneman, 2003; Hottenrott and Peters, 2012). In this context, *supply-push* measures may provide firms with sufficient funds to implement private innovative investments (Bronzini and Piselli, 2016).

Thanks to data provided by the Community Innovation Survey, the effect of different public policies has been included in the analysis of the role of public intervention in shaping EI dynamics. In so doing, a significant step forward has been made in the direction of understanding the diversification of the impacts exerted by environmental and innovation policies on EI, especially for *pollution-reducing* and *energy-improving* classes (where the latter are supposed to decrease the use of materials or energy per unit of output, while the former are expected to reduce negative externalities, such as reduction of air, soil, water and noise pollution and dangerous materials without *input-improvement*s). These two typologies have been found to be inherently different, either in the policy drivers. For example, Veugelers (2012) using data from CIS 2006-2008 for a sample of 2.894 Flemish firms, claims that *supply-push* government instruments are less effective in spurring the adoption of *pollution-reducing* and *energy-improving* technologies, while environmental policies (regulation and taxes) turn to be always relevant. Horbach (2016) exploits data from CIS 2006-2008 to analyze the determinants of EI in 19 countries. His main finding is that regulation factors are more important for *pollution-reducing* technologies, while their influence on *energy-improving* technologies appears to be less relevant. This result seems to be stronger for countries located in Eastern Europe, where the concentration of *pollution-reducing* technologies is supposed to be higher because firms face lower levels of environmental standards. Moreover, this category appears positively correlated with *supply-side* measures (mainly subsidies) while, on the contrary, *efficiency-improving* EI turns out to be more related to cost-saving considerations. Analogous findings have emerged in a narrowed analysis focusing on the German case (Horbach et al., 2012). In a similar framework, Doran and Ryan (2016) assess the causal correlation between EI and three groups of drivers: demand-side, supply-side and regulatory variables. The authors draw data from CIS 2008-2010 referring to a sample of 2.127 Irish firms. They find that the group of regulatory variables, including existing and expected regulation and environmental drivers, is of importance for both typologies.

Moving to *demand-side* measures, rationales for this class of innovation policies are provided by the existence of uncertain demand for green technologies, a market-failure which is partly related to government policy unpredictability (Kemp, 2000). In this case, the main operative tool is Green Public Procurement (GPP). Namely, it consists of the introduction of environmental criteria into tendering procedures in the view of reducing the environmental impact of public purchases, especially for those sectors responsible for high environmental impact, such as transport, buildings and furnishings. In principle, by setting sustainability requirements in public tendering, the use of public demand for greener goods and services may enlarge market opportunities for existing environmental-friendly products, thus providing new stimuli for environmental innovation through the creation of a minimum critical mass for sustainable goods and services that, otherwise, would difficulty get into the market.

Despite of the importance of this policy tool, scarce evidence has been provided about the role of procurement in sustaining the engagement in innovation activities (Aschhoff and Sofka 2009; Guerzoni and Raiteri, 2015; Crespi and Guarascio; 2017), and even less attention has been paid towards Green Public Procurement. In this respect, Cheng et al., (2018) recognize an overall lack of theoretical and empirical analysis devoted at assessing GPP as environmental policy instrument, as well as to fully understand its innovation properties. Though not focused on GPP, a contribution in this direction has been provided by Ghisetti (2017), where a positive and significative impact of contracts of public furniture with innovative requirements on EI adoption has been found for manufacturing firms belonging to different European countries.

3. Research questions

Existing research has shown that both environmental and innovation policies may influence firm's ability in introducing green technologies. As above argued, much literature has pointed the attention on the dichotomy between *pollution-reducing* and *energy-improving* innovations by investigating, among other issues, their links with environmental and innovation policy drivers. In general, the existing empirical evidence shows that, regarding environmental policy tools, CACs are of importance for *pollution-reducing* activities while MBIs appear mainly associated, although less frequently, with *energy-improving* innovations. Moreover, the latter turn out to be positively correlated with innovation tools and, in particular, with *supply-side* tools while the impact of *demand-side* measures is still scarcely investigated.

In this framework, though an extensive bulk of studies highlights the primary role of public policies in shaping eco-innovation dynamics, there is still space to deep investigate the link between policy and EI by introducing in the analysis the issue of heterogeneity among green innovation strategies.

This hint stems from a recent stream of literature claiming that firms engage in different "modes" of EI instead of following a unique pattern. This aspect is well underlined by two recent empirical studies.

The first is a study by Marzucchi and Montresor (2017), who look at the "technological" side of EI by exploiting the STI (science-technology innovation) and DUI (doing users innovation) dimensions. In retaining the diverse nature of EI targets, the scholars distinguish efficiency (material and energy reducing process innovations) and non-efficiency related (e.g. *end-of-pipe* technologies) process innovation from green product innovations. The paper draws data from two non-overlapping waves of Spanish Innovation Panel (PITEC) that covers a sample of 4.700 manufacturing firms for the period 2007-2012. Their major finding concerns the so-called hybrid innovation mode, which consists of a combination of STI and DUI that firms are likely to adopt when introducing environmental innovations. In this regard, since as different configurations of STI and DUI correspond to distinct environmental innovations, the scholars conclude that, according to the final objective, each EI strategy requires its specific composition of internal and external knowledge sources. For example, while *R&D-based* knowledge is pivotal for all innovations, *not-R&D based* embodied knowledge (i.e. physical and human capital investments) appears to be relevant only for efficiency related-EI. In contrast, non-R&D based disembodied knowledge (i.e. marketing investments) is mainly associated with non-efficiency EI and green product innovations. Furthermore, by looking at the external sources, cooperation with not scientific partners (i.e. firms in the same groups, suppliers, competitors and customers) turns out to be important for both non-efficiency related EI and green product innovations, while technological cooperation practices (i.e. interaction with universities, private R&D institutes and laboratories, public research organizations) seems to influence only efficiency related EI.

In parallel, the issue of heterogeneity among green innovators clearly emerges in the analysis by Castellacci and Lie (2017), who put the emphasis on the crucial role of active policy efforts in inducing firms to start to invest more actively in green innovations. In a more detail, the authors drawn data for 1.719 manufacturing firms from the 2008 Korean Innovation Survey and build a four-cluster taxonomy of green innovators. The four groups have been found to differ one each other, even in terms of policy drivers. The categories are: *energy-saving* firms associated with high R&D capabilities and strong network with universities, *waste-reducing* and *recycling* firms linked to both market drivers and R&D policies and, finally, *pollution-reducing* firms, that are mainly triggered by environmental regulation.

Both studies are particularly worth of noting, as they demonstrate that a better understanding of EI policy determinants strictly relies on the ability to identify EI patterns, thus avoiding establishing *ex ante* too broad or too narrow categories.

Building on the above considerations, the present paper proposes a similar clustering framework which allows for assessing the heterogeneity of EI strategies for the Italian case. After that, the analysis tries to shed further light on the effectiveness of public policies as EI-enhancing tools, by looking at the whole array of policy measures, such as CACs, MIBs, *supply-side* and *demand-side* measures.

In so doing, the following research questions will be addressed:

1) Do firms' environmental innovation strategies vary according the environmental impact they aim to achieve?
2) Do different public policies display a differentiated effects on EI activities according to the innovation mode followed by innovators?

4. Empirical Analysis

Data

The empirical analysis consists of two stages. The first one is dedicated to identifying distinct environmental innovation strategies (EI modes) (research question 1), while the second step investigates the link between the four categories of policy tools and distinct EI strategies (research question 2).

The dataset is based on data collected by the Italian Community Innovation Survey referred to the period 2012-2014. In particular, the 7th Italian CIS survey exploited for this analysis provides data on 17.532 firms belonging to manufacture and service sectors. Firms with at least 10 employees are identified through a stratified random sampling based on size, sector and geographical coordinates, while a census survey includes all firms with more of 249 employees. The web-based questionnaire is about 12 pages long and the response rate for wave 7^{th} has been of 62,8%. The analysis has been restricted to manufacturing firms and the final sample is composed by 4.792 units.

In comparison with previous CIS waves, CIS7 has made up a step forward in the investigation of firms' environmental innovation strategies by collecting information on a wide range of aspects related to EI. Indeed, firms are asked about the type and the goals reached by the environmental innovation carried out over the three-year period as well as the degree of importance attached to its drivers (policy factors, private demand, cost-saving considerations and reputational motivations). In addition, the generic innovation-related module provides a set of quantitative and qualitative data about firm's technology innovation strategy, including information on firm's R&D activities and cooperation practices.

First-stage analysis

The identification of the distinct EI modes follows the approach proposed by Castellacci and Lie (2017) which consists of a clustering procedure preceded by a Principal Component Analysis. The PCA is carried out on ten variables (Table 1): six referring to the achievement of environmental benefits experienced within the enterprises by innovating (namely ECOMAT, ECOENO, ECOPOL, ECOSUB, ECOREP, ECOREC) and four referring to the achievement of environmental benefits experienced during the consumption or use of a good or service by the end user by innovating (i.e. ECOENU, ECOPOS, ECOREA, ECOEXT). The sample is composed by 1.807 manufacturing claiming to introduce at least a process or product environmental innovation over the period 2012-2014.

Standardization process

By looking at Table 2, which reports the total of the environmental goals achieved by EI innovators, a clear trend of complementary between distinct goals emerges. As shown by the high pairwise correlations among the ten variables reported in Table 3, the complementarity could be due to the high degree of complexity and closely which is usually associated with green technologies.

Table 1. Ten types of environmental goals: Descriptive statistics

Variable		Mean	S. Dev	Min	Max	Freq
Environmental benefits obtained within the enterprise						
ECOMAT	Reduced material use per unit of output produced	.5307139	.4991939	0	1	959
ECOENO	Reduced energy use or ENERGY 'footprint' by firm	.71057	.4536234	0	1	1.002
ECOPOL	Reduced air, water, noise or soil pollution related to the production	.6043165	.4891324	0	1	1.350
ECOSUB	Replaced materials with less polluting or hazardous substitutes	.5002767	.5001383	0	1	1.151
ECOREP	Replaced fossil energy with renewable energy sources	.2047593	.4036373	0	1	955
ECOREC	Recycled waste, water, or materials related to the production	.3768677	.4847355	0	1	982
Environmental benefits obtained by the end user						
ECOENU	Reduced energy use or ENERGY 'footprint' by the end user	.5168788	.4998534	0	1	827
ECOPOS	Reduced air, water, noise or soil pollution by the end user	.4360819	.4960349	0	1	572
ECOREA	Recycling of product after use by the end user	.2999447	.4583603	0	1	711
ECOEXT	Extended product life through more durable products	.3680133	.4823985	0	1	665

Table 2. Number of environmental goals reached by CIS7 manufacturing firm

# of environmental goals	Freq.	Perc. (%)	Cum. Perc. (%)
1	152	8.41	8.41
2	287	15.88	24.29
3	291	16.10	40.40
4	252	13.95	54.34
5	207	11.46	65.80
6	195	10.79	76.59
7	172	9.52	86.11
8	111	6.14	92.25
9	85	4.70	96.96
10	55	3.04	100
Total	1.807	100	

Table 3. Correlations coefficients between environmental goals

	MAT	ENO	POL	SUB	REP	REC	ENU	POS	REA
MAT	1.000								
ENO	0.4731	1.000							
POL	0.3872	0.4818	1.000						
SUB	0.1790	0.1038	0.3281	1.000					
REP	0.1322	0.3872	0.3292	0.2708	1.000				
REC	0.3663	0.1849	0.3316	0.2807	0.2569	1.000			
ENU	0.1755	0.4153	0.2064	0.1334	0.2691	0.1421	1.000		
POS	0.1651	0.1954	0.5696	0.2663	0.2816	0.2419	0.7356	1.000	

REA	0.2260	0.0934	0.2303	0.3706	0.2554	0.4480	0.3683	0.4463	1.000

Note: Sample of green innovators only: n =1807. Tetrachoric correlation

Thus, before performing the Principal Component Analysis, a standardization process is needed to establish if and to what extent a given EI strategy is focused on a specific environmental goal. In detail, the standardization rule is distinctly applied on two groups of variables: IEB (internal environmental benefits) and EEB (external environmental benefits). For both, each of the six (four) variables referred to the benefits experienced within firms (by the end use) is divided by the total number of the environmental goals reached within firms (by the end use) by means of the innovation introduced. Formally:

$$IEB_y = \frac{IEB_y}{\sum_i IEB_y}$$

$$EEB_x = \frac{EEB_x}{\sum_i EEB_x}$$

(1)

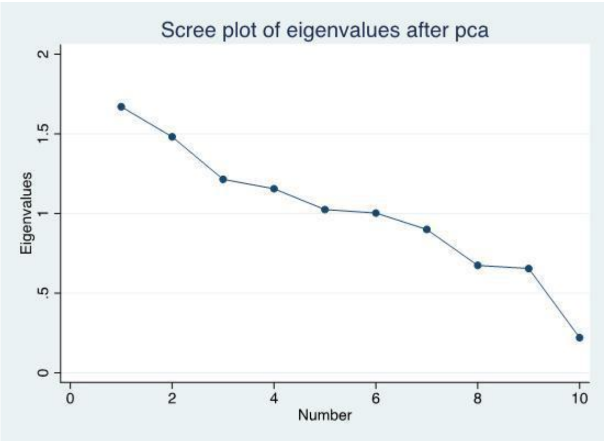
This standardization rule allows to identify distinct EI technological trajectories by assigning higher values to focused innovators, i.e. with narrow EBs, and lower values to those developing broader EI strategies, i.e. associated with the achievement of more than one EB. In so doing, environmental innovators are grouped on the basis of the predominance assigned to specific internal and external environmental targets by the innovator.

Table 4. Results from PCA

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	**1.67052**	**.188764**	**0.1671**	**0.1671**
Comp2	**1.48176**	**.267153**	**0.1482**	**0.3152**
Comp3	**1.2146**	**.0590894**	**0.1215**	**0.4367**
Comp4	**1.15552**	**.130689**	**0.1156**	**0.5522**
Comp5	**1.02483**	**.0216984**	**0.1025**	**0.6547**
Comp6	**1.00313**	**.103102**	**0.1003**	**0.7550**
Comp7	.900026	.225697	0.0900	0.8450
Comp8	.67433	.0196632	0.0674	0.9125
Comp9	.654666	.434042	0.0655	0.9779

Note: Factors with eigenvalue higher than 1 extracted. The final factors together explain 75.50% of total variance.

Figure 5. Scree plot of eigenvalues after PCA



As reported by Table 6, the first factor combines the two variables representing the *pollution-reducing* activities (ECOPOL and ECOPOS). The second factor has very high loading on the two variables measuring recycling innovations (ECOREC and ECOREA), implemented in order to reduce waste streams at both firms and users' level. The third and fourth factors are positively correlated with process and product *energy-saving* innovations (ECOENU and ECOENO), respectively. The fifth principal component has a very high loading on the indicator referring to material-reducing innovations (ECOMAT). Finally, the sixth factor is positively correlated with the variable which measures the replacement of a share of fossil energy with renewable energy sources (ECOREP). Because of the above six indicators are, by construction, independent of each other, it is possible then to reduce the ten highly correlated initial variables to six uncorrelated dimensions.

Table 6. Results of factor analysis (factor loadings)

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
	Pollution Reducing	*Recycling*	*Process Energy Improving*	*Product Energy Improving*	*Material Reducing*
ECOMAT	-0.0824	-0.0838	0.1310	0.0502	**0.8782**
ECOENO	-0.3574	-0.2065	**0.4015**	0.2073	-0.4194
ECOPOL	**0.6315**	-0.1186	0.1956	-0.2018	-0.1647
ECOSUB	-0.0772	-0.0708	-0.8423	0.0107	-0.1172
ECOREP	-0.0036	-0.0487	0.0664	0.0177	-0.0727
ECOREC	-0.0100	**0.7017**	0.2155	-0.0995	-0.0385
ECOENU	-0.1208	-0.1408	0.0271	**0.6166**	0.0393
ECOPOS	**0.6162**	-0.0359	-0.0544	0.1889	0.0486
ECOREA	-0.0779	**0.6134**	-0.1370	0.0834	-0.0050
ECOEXT	-0.2455	-0.1975	0.0232	-0.6932	0.0355
% of variance	0.1671	0.1482	0.1215	0.1156	0.1025

Note: Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. The numbers in bold indicate the variables that are more strongly correlated to each principal component.

Cluster Analysis

Finally, to properly identify distinct EI modes, a cluster analysis on the above six principal components is performed in two steps. Firstly, different solutions from several hierarchical methodologies are exploited to identify the optimal number of clusters (Hair et al, 2009). After comparing several clustering solutions ranging from two and eight, the optimal number has been chosen on the basis of their statistical significance and economic interpretation. The selected clustering method is the *complete-linkage*, which allows to minimize the within-cluster distance between observations. This strategy identifies a four-cluster solution as the most appropriate for our data. Secondly, a k-means clustering algorithm is applied to assign firms to clusters by imposing a four-cluster solution, as indicated in the previous phase. The results of the cluster analysis are reported in the Table 7.

Table 7. Results of cluster analysis (k-means clustering algorithm), mean values of principal components in each cluster

	CLUSTER 1	**CLUSTER 2.**	**CLUSTER 3.**	**CLUSTER 4.**
1. Pollution Reducing	**1.320591**	-.1860839	-1.425.237	-.4230929
2. Recycling	-.4828052	**1.054614**	-.8884444	-.4446957
3. Process Energy-saving	.1235243	-.5832346	**.841769**	.2302839
4. Product Energy-saving	.3246416	-.2266613	**1.540887**	-.7179422
5. Material Reducing	-.4052693	-.1443267	-.7045328	.8860314
6. Fossil energy_substituting	.0975199	.1427636	-.0634804	-.2439655
Freq.	481	613	219	494
Percent.	26.62	33.92	12.12	27.34

Cum.	26.62	60.54	72.66	100.00

The first group has a very high mean value for the first principal component analysis and identifies a large group of enterprises (481) introducing *pollution-reducing* innovations. The second cluster scores very high on the second principal component *recycling*, thus identifying 613 firms that carry out innovations to reduce the waste streams during the production process and new recycling technologies experienced by end-users. The third cluster has above-average values on the third and fourth components, classifying a less numerous groups of firms (219) that innovate along the *energy-saving* technological trajectory. Finally, the fourth cluster loads very high for the fifth principal component (material reducing), thereby identifying a group of firms that predominantly introduce *material-reducing* innovations. This latter group encompasses 494 firms.

Econometric analysis & Results

The characteristics of the four groups are detected by the econometric analysis (Table 10). The latter is carried out by running out four logistic regression models which estimate the probability of belonging to a given cluster. A set of CIS drivers grasping different dimensions affecting firms EI behaviors are using as regressors to perform the analysis (Table 8 and 9). The logistic regression could be formally expressed as follow:

$$\mathrm{P}rob\ (Yi = 1) = 1/(1 + \sum_k exp(\beta_k^T X_i)) \qquad \textit{for each j=1} \qquad (2)$$

where Y_i represents the set of clusters obtained from cluster's analysis, the vector X_i of explanatory variables and ${}_j$ reflects the vector of estimated coefficients for each cluster j.

Table 8. Drivers of green innovations

Variable	Description
Environmental policies	
CACs	High/medium importance of existing regulations on pollution*
MIBs	High/medium importance of existing taxes on pollution*
Innovation policies	
Supply-push	High/medium importance of government grants, subsidies or other financial incentives*
Demand-pull	High/medium importance of requirements for public procurement contracts *
Other drivers	
Reputation	High/medium importance of enterprise's reputation*
Cost-saving	High/medium importance of cost of energy, water or materials*
Private demand	High/medium importance of current or expected market demand*
Voluntary codes	High/medium importance of voluntary codes or agreements*
Sources of innovation	
Internal R&D	Intramural R&D (1 yes; 0 no)
Technological Cooperation	Cooperation arrangements on innovation with scientific partners (1 yes 0 no)
Not Technological Cooperation	Cooperation arrangements on innovation with not scientific partners (1 yes; 0 no)
Firms' characteristics	
Size	Log of turnover (mean value 2012-2014)
Export	Export activities (2012 - 2014), (1 yes; 0 no)
Group	Group belonging (2012 - 2014), (1 yes; 0 no)

**(1 high/medium, 0 no)*

Note: Sample of green innovators only: n =1807. The first 7 variables are from the special module on green innovation provided by CIS7. The remaining variables are from the general survey and thus refer to the firm and their general innovation activities, rather than green ones specifically.

The first set of regressors concerns environmental policies tools, grouped in CACs and MBIs. Specifically, CACs instruments are represented by exiting environmental regulation, while MBIs instruments are identified in the exiting environmental taxation. The second set of regressor embraces innovation policy instruments, respectively represented by *supply-push* measures, such as government grants, subsidies or other financial incentives, and *demand-pull* tools referring to specific requirement to meet within public procurement contracts. All the above indicators have been transformed in dichotomous variables that take value equal to 1 if firms assign them medium or high level of importance (value 2 and 3 of the Likert scale), and 0 otherwise. The third set of variables takes into account other drivers as firm's reputation, cost saving motivations, demand from private actors and voluntary code, firm's technological capabilities (represented by internal R&D and technological and not technological cooperation activities with external partners) and finally, firms' individual characteristics, such as size, group and export dummies. Sectoral dummies calculated at a NACE 2-digit are included as regressors.

The main result of the econometric analysis is that policy drivers differently score across the four EI modes, thus confirming that eco-innovating patterns are inherently different. Regarding the role played by environmental policy tools, findings emerging from Table 9 show a strong and positive correlation between CACs and the probability of belonging to cluster 1. In line with empirical evidences by Frondel et al. (2007) and Demirel and Kesiduo (2011), CACs instruments have been found to affect the introduction of less radical innovations, as in the case of *pollution-reducing* technologies that are usually included in the class of *end-of-pipe* technologies.

By looking at innovation policies, the role of *supply-push* measures turns out to be positively associated with *energy-saving* innovations, while *demand-pull* policies are found to positively affect *recycling* innovators. These findings may be explained by two facts.

First, *energy-saving* technologies achieve the double aim to reduce pollution while improving energy-performance, so that, their realization may involve a more complex and radical innovation process which, in turn, implies high degrees of riskiness that may discourage external investors. In this view, firms engaging in *energy-saving* innovations may make use of public financial sustain to a greater extent than those engaging in other, less risky, EI activities. This finding is inconsistent with evidences provided by Veugelers (2012) and Horbach (2008, 2016) where, contrary to the present analysis, use an *ex-ante* classification to unify *energy-saving* and *material-reducing* technologies into a single *efficiency-improving* class.

Second, green public procurement procedures, which essentially follow the LCA approach (Life Cycle Assessment), basically sustain recycling practices for minimizing services and products' environmental impact throughout their whole life cycle, i.e. from the materials production stage to the end-of-life. In this context, the need of meeting environmental criteria, as required by the public tendering, may represent a significant stimulus for the engagement in recycling practices aimed at realizing more eco-friendly goods and services.

Surprisingly, any correlation has been found between policy drivers and cluster 4 encompassing *material-reducing* innovators. This means that firms following this pattern are not triggered by policy factors and other external drivers, as reputation and cost considerations. Rather, the *material-reducing* trajectory is likely to stem from an "unconditioned" pace of technological progress.

To better explain these findings, Table 11 summarizes the main characteristics as follows:

(i) *Pollution-reducing EI*. This mode is followed by 481 firms that attach great importance to CACs policies. However, a weak but significant impact on the probability of belonging to this cluster also arises from the *supply-push* indicator. Furthermore, compared to other environmental innovators, *pollution-reducing* innovators are found to be smaller and to belong to a group.

(ii) *Recycling EI.* This group is the most numerous one since it includes 613 environmental innovators aiming at recycling goals at both process and product level. When compared to other eco-innovators, these companies turn out to be triggered by *demand-side* innovation policies and voluntary codes. In contrast, the exploitation of *supply-side* tools appears negatively correlated with the odds of belonging to this group. Finally, recycling innovators are bigger than others and seem to show an own property structure.

(iii) *Energy-saving EI*. This cluster is the smallest one by consisting of 219 firms. For the group, the crucial policy driver is represented by financial support by governments. On the contrary, *energy-improving* innovations are not fueled by green public purchasing as well as environmental standards impositions. In addition, cost-saving motivations are also relevant for being part of this cluster.

(iv) *Material-reducing EI.* This mode is followed by 494 firms. The probability of belonging to this group increases for companies that assign less or null importance to policy drivers, especially to CACs and *supply-push* measures. In addition, firms belonging to cluster 4 are less propense to cooperate with external partners and, as reported by Table 9, show the higher mean value for the internal R&D variable.

Table 9. Mean values of driver variables for each cluster

	CLUSTER 1. Pollution Reducing	**CLUSTER 2.** Recycling	**CLUSTER 3.** Energy improving	**CLUSTER 4.** Material Reducing
Environmental policies				
CACs	**.7671518**	.7585644	.543379	.6639676
MIBs	.3243243	**.3784666**	.2283105	.3137652
Innovation policies				
Supply-push	.4345114	.4045677	**.4611872**	.3684211
Demand-pull	.2390852	**.3050571**	.1506849	.2186235
Other drivers				
Reputation	.7733888	**.8384992**	.6712329	.7813765
Cost-saving	.7089397	.7422512	**.7808219**	.7489879
Private demand	.5301455	**.5742251**	.4200913	.4777328
Voluntary codes	.3305613	**.4681892**	.2511416	.3076923
Internal R&D	.6528067	**.7014682**	.652968	**.7145749**
Technological Cooperation	.2453222	**.3050571**	.283105	.2469636
Not Technological Cooperation	.0561331	.0603589	**.0684932**	.0587045
Size	1.689.975	**1.711.339**	1.671.979	1.694.391
Export	.8939709	.9200653	.9178082	**.9271255**
Group	**.7920998**	.7487765	.7260274	.7550607

Numbers in bold indicate the clusters with higher mean value for the specific variables

Table 10. Results from logistic regressions

	CLUSTER 1.	**CLUSTER 2.**	**CLUSTER 3.**	**CLUSTER 4.**
Environmental policies				
CACs	**0.102*** **	0.036	**-0.062*** **	**-0.058** **
	(0.03)	(0.03)	(0.02)	(0.03)
MBIs	-0.032	0.025	-0.023	0.030
	(0.03)	(0.03)	(0.02)	(0.03)
Innovation policies				
Supply-push	**0.040***	**-0.060** **	**0.055*** **	**-0.038***
	(0.02)	(0.02)	(0.02)	(0.02)
Demand-pull	-0.013	**0.057** **	**-0.044** **	-0.011
	(0.03)	(0.03)	(0.02)	(0.03)
Other drivers				
Reputation	-0.022	0.047	**-0.043** **	0.033
	(0.03)	(0.03)	(0.02)	(0.03)
Cost-saving	**-0.040***	-0.032	**0.042** **	0.027
	(0.02)	(0.03)	(0.02)	(0.02)
Market demand	0.031	0.014	-0.014	-0.027
	(0.02)	(0.02)	(0.02)	(0.02)
Voluntary codes	**-0.043***	**0.113*** **	-0.028	**-0.053** **
	(0.02)	(0.02)	(0.02)	(0.02)
Internal R&D	-0.034	0.006	-0.011	0.040
	(0.02)	(0.03)	(0.02)	(0.02)
Technological Cooperation	-0.025	0.042	0.023	**-0.043***
	(0.03)	(0.03)	(0.02)	(0.03)
Not Technological Cooperation	-0.035	0.033	0.015	-0.015
	(0.05)	(0.05)	(0.03)	(0.04)

Size	**-0.013***	**0.023*****	-0.009	-0.000
	(0.01)	(0.01)	(0.01)	(0.01)
Export	-0.056	0.001	0.023	0.033
	(0.04)	(0.04)	(0.03)	(0.04)
Group	**0.090*****	**-0.076****	0.004	-0.015
	(0.03)	(0.03)	(0.02)	(0.03)

Note: Reported are marginal effects at the sample mean
* p<0.10, ** p<0.05, ***p<0.01

Table 11. Summary of the most important characteristics of each cluster of green innovators

	CLUSTER 1. *Pollution Reducing*	**CLUSTER 2.** *Recycling*	**CLUSTER 3.** *Energy-improving*	**CLUSTER 4.** *Material Reducing*
Strongest policy drivers	CAC environmental policies	Demand-side innovation policies	Supply-push innovation policies	None
Weakest policy drivers	None	Financial support	CAC environmental policies; Demand-side innovation policies	CAC environmental policies; Supply-push innovation policies
Other drivers	Groups belonging; Small firms	Own propriety; Large firms	Cost-saving	None

5. Conclusions

In the European context, the transition towards a “resource efficient and greener economy” has been settled as a key priority (EU, 2011) by the Lisbon Agenda and Europe 2020.

To sustain such a convergence between environmental and economic issues, policy action plays a primary role in providing firms with effective stimuli to develop environmental-friendly technological. The need for public intervention is justified by the presence of many market-failures hindrances, that are supposed to affect EI to a greater extent than standard innovation. On the one hand, the “double externality problem” makes the typical appropriability problem of innovation exceptionally pronounced when green technologies are implemented as firms bear the costs of less pollution while the society benefits from it (Beise and Rennings, 2005). On the other hand, since as EI activities belong to a less mature field of innovation when compared to traditional technologies (Ghisetti et al., 2015), EI investments are perceived to be highly risky (Kapoor and Oksnes, 2011) and, as a consequence, external investors may be less attracted by them. All these conditions provide strong rationale for adopting policy measures.

The present paper goes in this direction by exploiting a wide array of policy instruments and their link with EI by accounting for heterogeneity among distinct EI patterns followed by firms. In so doing, a much richer and complex picture of environmental innovation domain is provided through the identification of four eco-innovation modes, namely (1) pollution-reducing, (2) recycling, (3) energy-saving and (4) material reducing, whose implementation turns out to be in most of these cases, positively correlated with environmental and innovation policy tools.

The main results of the exploratory exercise can be synthesized as follows:

(i) By paying attention on environmental policy drivers, it emerges that those firms grouped in cluster (1) are mainly driven by regulatory instruments (CACs) belonging to the environmental policy class. Consistent with previous analysis, this result confirms that environmental policies success in sustaining less radical EI activities, as in case of *pollution-reducing* technologies. In contrast, any significant relationship emerges for MBIs (environmental taxation), thus signaling that the price of polluting might be not sufficiently high to stimulate innovation activities with beneficial environmental effects. This arises the need to interview under the aspect of the fiscal design.

(ii) With respect to innovation policy instruments, evidences of positive links with EI have been recognized in two cases. First, *energy-saving* technologies (3) appear to benefit from *supply-push* measures while recycling innovations (2) are positively stimulated by *demand-pull* policies. Both results are in line with theoretical speculations about the corrective role of *supply-side* policies (especially in case of more complex innovation projects as *energy-saving* innovations) and the positive impact of green public demand in successfully stimulating recycling practices through the LCA approach.

(iii) With respect to other external drivers, it emerges that voluntary codes are relevant for cluster (2), while cluster (3) basically attaches more importance to cost-saving considerations and reputational motivations.

These findings give response to the research questions made in section 3, with some important contributions for the development of EI related literature. Firstly, thanks to the identification of distinct innovation patterns, a more complete representation of EI realm has been provided for the Italian case. Secondly, the key role of public policies in stimulating EI practices has been found to change in sign and magnitude across EI policy tools and modes.

This means that, to increase policy efficiency, distinct policy actions should be set according to specific environmental targets (pollution-reducing, recycling etc..). In other words, this would make environmental and innovation policies more effective leverages to increase sustainability.

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