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Characterizing the policy mix and its impact on eco-innovation in energy-efficient technologies*

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Abstract

This paper provides an empirical investigation of the role played by selected characteristics of the policy mix in inducing innovation in energy efficiency technologies. An original dataset covering 23 OECD countries over the period 1990-2010 combines the full set of policies in the energy efficiency domain for the residential sector with data on patents applied over the same period in this specific technological sector. The evidence of a positive policy inducement effect on innovation dynamics is enriched by the following main results: i) policy mix comprehensiveness is influential since countries adopting different instruments show a relatively higher positive inducement effect; ii) inconsistency problems between the different tools forming the policy mix may negatively influence innovation activities when the variety of policy instruments becomes excessive; iii) the different instruments forming the policy mix need to be well balanced in their relative strength in order to reduce potential negative lock-in effects; iv) the greater the external balance of the national policy strategy with the policy setting of other similar countries, the higher the inducement effect on the technological dynamics of the investigated country. Several suggestions for implementing effective policy strategies can be made in this case study that can be potentially extended to other technology domains.

Keywords: eco-innovation; policy mix; policy spillovers; energy efficiency; residential sector

J.E.L. O31, O38, Q48, Q55, Q58

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1. Introduction

The analysis of how different technological domains broadly classified as the eco-innovation field have evolved in recent years is attracting growing attention both at academic and policy level.[1] The current debate has adopted distinguished analytical perspectives in order to better understand the dynamics, characteristics, and determinants of eco-innovation (Arundel and Kemp, 2009; Beise and Rennings, 2005; Berkhout, 2011; Cainelli and Mazzanti, 2013; Kemp and Oltra, 2011; Marin, 2014; Markard *et al*., 2012; OECD, 2011; van den Bergh *et al*., 2007; Wagner, 2007). These studies suggest that a variety of factors drive eco-innovation but also highlight the primary role played by public policies (environmental regulation, energy and technology policies) that are increasingly used to foster the rate of introduction and the diffusion of new environmental technologies to meet sustainable development goals (del Río, 2009a; Horbach *et al*., 2012; Johnstone *et al*., 2010; Mowery *et al*., 2010; Newell, 2010).

The bulk of previous literature has focused attention on the impact of single (though different) policy instruments mainly belonging to the two broad categories of demand-pull and supply-push instruments (Bergek and Berggren, 2014; Horbach *et al*., 2012; Kemp and Pontoglio, 2011; Peters *et al*., 2012; Rennings, 2000). Recent empirical contributions demonstrate that these instruments have differentiated impacts on the diverse types of innovative activities such as those related to the introduction of incremental or radical innovations (Nemet, 2009) or associated with technological exploitation or exploration activities (Costantini *et al*., 2015; Hoppmann *et al*., 2013). However, there is growing interest in understanding the role played by the different combinations of the available policy instruments in stimulating and directing technical change. In particular, the literature has recently focused on the role of policy mix and the consequences of policy interactions and interdependencies between different policy instruments (Flanagan *et al*., 2011, Rogge and Reichardt, 2013). In this respect, policy mix studies applied to eco-innovation domains tend to be limited in examining the effects of the mix design and instrument interactions (del Río and Hernández, 2007; IEA, 2011a,b) and further empirical analysis is required in order to assess the contribution of policy instrument interaction in a systemic view (Coenen and Díaz López, 2010).

Following recent contributions based on detailed case studies or firm level surveys that explore the possibility of analysing the impact on eco-innovation produced by the policy mix and its characteristics (Mattes *et al*., 2014; Reichardt and Rogge, 2014), here we propose a quantitative analysis based on a large sample of OECD countries aimed at measuring some relevant characteristics of the policy mix and quantifying their impact on innovation activities through panel data econometrics. In doing so, we contribute to the literature by developing a characterization of the policy mix that attempts to be both informative and measurable in order to analyse the innovation effects not only of policy mix elements but also of its characteristics, thus deriving new policy insights into how to design policy mix in order to foster the development of environmental-friendly

[1] The terms eco-innovation, green technologies, environmental innovation are used interchangeably in this paper.

technologies.

This analytical perspective is applied to the Energy Efficiency (EE) technological domain, which appears to be particularly relevant since it is characterized by the interplay of a wide range of agents and policy instruments involved, acting in different directions and with different objectives. As a matter of fact, the pervasiveness of energy consumption in the whole socio-economic context (from private consumers to large scale manufacturing production) confers to this technological domain some specific features that should be carefully investigated when a complex policy strategy is designed (Costantini and Mazzanti, 2012). The complexity of this domain deserves a specific effort in developing an appropriate analytic framework in order to capture the large number of linkages influencing the dynamic pattern of technological activities (del Río and Hernandez, 2007; Florax *et al*., 2011). For this purpose, our approach aims to complement standard policy innovation inducement analyses with a deeper investigation of how the characteristics of the policy mix influence the technological trajectories in this domain.

The remainder of the paper is organized as follows. Section 2 provides a literature review on policy inducement effects in eco-innovation and most recent developments in the analysis of policy mix strategies. Section 3 describes the proposed characterization of the policy mix in the case of EE technologies, whereas Section 4 lays out the research hypotheses and econometric strategy. Section 5 presents the econometric results of the impact of the characteristics of the policy mix on eco-innovation in EE technologies. Finally, Section 6 summarizes the main insights emerging from the study, highlights the policy implications and outlines possible further research lines.

2. Policy inducement effects in eco-innovation and the role of the policy mix

A large number of economic studies have been devoted to identifying the determinants of eco-innovations, analysing the different elements that contribute to triggering firms' eco-innovation activities (del Rìo, 2009a; Foxon, 2003; Horbach, 2008; OECD, 2011). This has constituted an empirical issue that has given rise to a flourishing strand of literature in which the role of public policies has been found to be one of the most important drivers for spurring eco-innovation (Bergek and Berggren, 2014; Haščič *et al*., 2009; Johnstone *et al*., 2010, 2012; Schmidt *et al*., 2012).

In more detail, the literature has identified different types of policy interventions that have been classified in several categories. A first distinction refers to two broad categories of demand-pull and technology-push instruments. While technology-push instruments act to increase the supply of new knowledge, demand-pull instruments affect the size of the market demand for new technologies (see, among others, Costantini *et al*., 2015; Hoppmann *et al*., 2013; Horbach *et al*., 2012; Nemet, 2009; Rennings, 2000).

Another useful classification distinguishes between quantity-based policies (such as quotas and targets) and price-based support policies (such as feed-in-tariffs and tax exemptions). The former are usually considered to produce declining innovation incentives when standards tend to become nonbinding, while the latter are generally perceived as more capable of creating a constant demand for innovation (Kemp and Pontoglio, 2011; Menanteau *et al*., 2003; Requate, 2005).

Moreover, the literature distinguishes between prescriptive instruments and voluntary approaches. The first category includes mandatory policy schemes that alter the pay-offs of economic agents through, for example, the imposition of taxes or subsidies, the adoption of a specific technology or the introduction of pollution standards. On the other hand, instruments based on a voluntary approach (also called as "soft instruments") enhance the level of consumer awareness with respect to potential benefits deriving from specific behaviour (e.g. by adopting a cleaner technology or by being compliant with a regulation).

Finally, recent analyses of innovation dynamics, in particular when eco-innovation processes are under scrutiny, focus on the role of systemic instruments designed to influence the overall socio-economic and technology system to allow for adaptive strategies within institutional and technological contexts, fuelling the generation of eco-innovation and the green transformation of the economies (del Río, 2009a; Kemp, 2011; Nill and Kemp, 2009; Smith *et al*., 2010; Wieczorek and Hekkert, 2011). In particular, the complex interaction of policies that involve different regional levels, with multiple rationales and policy domains, may lead both to a governance gap or overlapping policy initiatives (Uyarra and Flanagan, 2010). In this respect, systemic approaches aim to solve system failures linked to coordination problems arising from interactive behaviours between different agents and institutions (Bleda and Del Río, 2013; Chaminade and Edquist, 2010; Metcalfe, 1995; Metcalfe and Ramlogan, 2008).

The empirical literature investigating the role of environmental policies and other types of policy instruments in shaping the dynamics of eco-innovation is extensive. A pioneering contribution is provided by Lanjouw and Mody (1996). They examine the relationship between patenting activity and environmental policy stringency and find that the latter induced innovation by increasing the number of patents. Jaffe and Palmer (1997) extend the study by Lanjouw and Mody (1996) by incorporating various factors that potentially affect environmental innovation. Although they find a positive relationship between environmental stringency and firms' research and development (R&D) expenditures, no effect is found on patents. Following this research line, Brunnermeier and Cohen (2003) investigate the relationship between changes in abatement and monitoring costs and specific environmental patents by analysing a panel dataset of 146 US manufacturing industries from 1983 to 1992. Unlike Jaffe and Palmer (1997), they find small but significant evidence that pollution abatement expenditures are positively correlated with successful environmental patent applications. Similar effects are also found in other studies. Popp (2002) observes patenting activities over the period 1970-1994 and deduces that higher energy prices, held up by market instruments (energy taxation), encouraged the substitution process in favour of new energy-efficient technologies. Crabb and Johnson (2007) analyse the effects of US fuel taxes on patents in the automotive sector in the period 1980-1999 and confirm the induced innovation hypothesis.

As the policy setting is growing both in qualitative and quantitative terms, permeating more and more eco-innovation domains, the empirical analysis is also increasingly enriched by considering the effects of the in force policy setting as a whole instead of looking at only specific instruments. Intrinsic characteristics such as the level of policy stringency and the degree of policy flexibility have been recognized as important factors in inducing firms to innovate in green technologies. For instance, Popp (2006) shows that command-and-control schemes seem to be less effective than market-based instruments in spurring eco-innovations in the US, Japan and Germany. Johnstone *et al*. (2010) provide significant evidence that policies such as feed-in-tariffs and renewable energy certificates, as well as public expenditures on R&D, positively affected the dynamics of patenting activity in a comprehensive sample of OECD countries. Nemet and Kammen (2007) also confirm the positive role of public R&D expenditures in energy efficiency.

However, while at a earlier stage governments could induce innovation by reducing the cost for innovating firms (technology-push policy approach) or by increasing the private payoff to innovators (demand-pull policy approach), more recently, the spectrum of policy options available for policy makers has notably increased as well as the influence of institutional factors (Triguero *et al*., 2013). Accordingly, the research agenda have followed a more complex and comprehensive approach to capturing the entire spectrum of in force policies and the intrinsic characteristics of the whole policy setting.

While there is a quite unanimous consensus on the positive inducement effect played by public policies on eco-innovation dynamics, there is still space for investigating how the type and the combination of different policy instruments influence innovation trajectories. As previously shown, existing eco-innovation studies that investigate the role of public policies take into account only one or a few policy instruments, without specifically examining the interaction between them.

Kemp and Pontoglio (2011) highlight that eco-innovation can take place in different contexts and involves several places and economic actors. Given the increasing complexity and intensification of policy interventions for eco-innovation, the final outcomes of government regulation are becoming more and more difficult to predict. For instance, what if the government, on the one hand, supports technology-push actions (e.g. through R&D subsidies to firms producing energy efficient appliances) and market-based interventions (e.g. through electricity taxation) but, on the other hand, does not stimulate households demand for cleaner appliances? In this (not uncommon) situation, the risk of policy failures and inefficient public expenditures constitute a growing concern for policy makers, especially in a context of a lack of resources due to public budget constraints associated with the economic crisis.

In this respect, a well-designed policy scheme should take into account several elements such as credibility, flexibility and ability of policies to learn from mistakes and successes. These features can determine the success or failure of a given policy framework (Mowery *et al*., 2010). More precisely, the analysis of policy design is becoming more strictly linked to the issue of policy mix.

Neither the term "policy mix", nor the intuition that different innovation policy instruments can interact, are new to the economic literature. Early studies attempt to investigate the complementarity mechanisms as well as the substitution or compensation effects among coexisting instruments (Branscomb and Florida, 1998; Howlett, 2005; Smith, 1994; Sorrell and Sijm, 2003).

The growing theoretic literature on policy mix is providing several insights, although many studies still adopt heterogeneous, and sometimes ambiguous, terminology (Quitzow, 2015; Rogge and Reichardt, 2013). The OECD (2010) develops a concept of policy mix consisting on the interaction and balance between and within the following four elements: the policy domains, the rationales offered in support of policy intervention, the strategic tasks pursued and the instruments deployed. In a similar vein, Flanagan *et al*. (2011) explain that the tools employed in a single policy setting should be designed in order to respect at least three characteristics: i) the overall policy mix needs to be comprehensive, ensuring the extensiveness and exhaustiveness of its elements; ii) instruments should be synergic in order to maximize and exploit potential complementary effects among different policy elements (consistency); iii) there must be coherence between the different inforce policy tools where the objective of each instrument should be in line with the others.

Building on the previous contributions, Rogge and Reichardt (2013) develop a more detailed and complete policy mix concept to be used as a starting point for informing policy makers when designing an appropriate instruments mix able to stimulate innovation dynamics. As a general consideration, it is extremely important to design a regulatory framework characterized by strong internal coherence and consistency between different policy instruments and across policy domains and actors involved (Cunningham *et al*., 2013; Dodgson *et al*., 2011).

In addition, a proper policy mix should be formed by instruments able to: i) stimulate and allow the participation of various actors, including users; ii) prevent lock-in and stimulate creative destruction; iii) prevent institutions that are too weak and too stringent; iv) stimulate physical and knowledge infrastructures (Smits and Kuhlmann, 2004; Wieczorek and Hekkert, 2011). To this end, Borras and Edquist (2013) emphasize the need to map and categorize the set of policy instruments so far employed at global level, which is growing in complexity and heterogeneity, since several so-called "soft instruments" (such as voluntary and non-coercive measures) are increasingly employed to complement more traditional market-based and command-and-control measures. In light of this reasoning, Crespi and Quatraro (2013, 2015) provide specific arguments on the importance of policy mix variety aimed at promoting new technology generation and able to address a sustainable growth path in an eco-innovation context.

This approach appears to be particularly important in long-term environmental problems where the high degree of complexity and uncertainty forces the policy framework to combine different policy tools and take into account the whole range of different actors including individuals, governments, national as well as international, and private and public institutions in order to increase the dynamic adaptability of the system (Coenen and Díaz López, 2010). Moreover, it poses great challenges to empirical research that needs to develop a systemic analysis able to capture the composition and interaction effects between the different instruments used to trigger eco-innovation, being both feasible from an empirical perspective and interpretable and informative for policy makers.

Empirical studies analysing the characteristics of the policy mix and the interactions, contradictions and final outcome of the whole effect of different types of policy instruments still represent a limited research area (Bergek and Berggren, 2014; del Río and Hernández, 2007; Flanagan *et al*., 2011). Only a few recent works, mainly following a qualitative approach, try to address these issues.

As a first qualitative analysis, Magro and Wilson (2013) develop a multi-step protocol applied to the specific case of the Basque region, finding relevant overlaps and complementarities between different policy instruments implemented with the same rationale by different administrative domains and levels. Although the authors admit that it is not possible to capture the entire range of potential interactions between innovation policies, their work represents a step forward in the derivation of a practical evaluation of the complex interactions existing in the policy space.

A second contribution, based on a quantitative approach, is provided by Guerzoni and Raiteri (2015) who assess the impact of different policy tools in 5,238 firms in the 27 EU member states, including Norway and Switzerland, using the propensity score matching method. The role of instrument interaction is explicitly considered in the empirical analysis and is found to significantly reinforce the impact of single policy instruments aimed at spurring firms' innovative activities.

More specific contributions to the analysis of policy mix and its characteristics in relation to the advancement of environmental technologies are provided by Mattes *et al*. (2014) and Reichardt and Rogge (2014). Mattes *et al*. (2014), using data from the German Manufacturing Survey, do not find significant evidence that policy mix plays a crucial role in shaping investments in renewable energy technologies in the observed sample. Reichardt and Rogge (2014) develop a qualitative company case study to analyse the innovation impact of the characteristics of the policy mix in the German off-shore wind sector. In contrast with Mattes *et al*. (2014), they find that the consistency of the policy strategy and the instrument mix is highly relevant in shaping innovation activities in the examined case.

Following this empirical literature, our paper aims to provide a contribution in this direction by presenting an econometric analysis based on a large set of country level data that provides us with new empirical evidence on the impact of policy mix characteristics on innovative activities applied to the domain of energy efficiency technologies in the residential sector. In so doing, we also try to make a first attempt to include the role played by foreign policies in the analysis, an aspect that has been rarely addressed (Dechezleprêtre *et al*., 2011; Popp, 2006) and which has not yet been considered by the literature examining the relationships between policy mix and eco-innovation.

Few empirical contributions focus their attention on the existence of cross-country policy spillover effects that may positively influence eco-innovation dynamics for selected domains. For instance, Lanjouw and Mody (1996) observe that strict regulations in the US for the vehicle emission sector spurred innovation in foreign countries such as Japan and Germany. Popp *et al*. (2011) examine chlorine-free technology in the pulp and paper industry and find a positive correlation between foreign regulation and innovation. Dechezleprêtre and Glachant (2014) identify positive policy spillover effects for innovation patterns in the wind power sector, whereas Peters *et al*. (2012) find similar effects for demand-pull policies in the photovoltaic energy sector.

In this paper we try to take these effects into account by looking at the alignment between the domestic policy mix and those of other countries, suggesting that in decisions concerning policy mix design, the coherence of domestic instruments and how they interact with instruments in the same field implemented at the international level must also be considered.

3. Research hypotheses and empirical strategy

3.1 Research hypotheses

Building on this debate, this study provides a first attempt to empirically evaluate the role played by the characteristics of the policy mix in shaping technological trajectories in energy efficient technologies in the residential sector. This sector appears to be an appropriate domain to be investigated since there are a large number of different policies in force in several countries, both demand-pull vs. supply-push and compulsory vs. voluntary (Costantini *et al*., 2014a; del Río and Hernandez, 2007; Florax *et al*., 2011). According to the reviewed debate on the policy inducement effect combined with the role of the characteristics of the policy mix, in the empirical investigation we have chosen a selection of issues to be analysed according to the specific features of the technological domain under scrutiny and data availability.

In particular, according to previous literature on policy mix and considering available information on the set of policy instruments related to energy efficiency objectives, we identify four characteristics of the policy mix that can be measured and whose specific impact on eco-innovation performances can be evaluated.

First, we try to evaluate the role played by the *comprehensiveness* of the policy mix, meaning how extensive the use of different policy instruments is, including not only standard demand-pull and technology-push tools but also, for instance, soft instruments such as voluntary and non-coercive measures (Rogge and Reichart, 2013). The inherent complexity of a policy framework aimed at enhancing energy efficiency suggests that a large range of instruments has to be implemented at the same time. Complementary or supplementary tools are in fact often needed to control for side effects or to reinforce the efficacy of the main instruments employed (del Río and Howlett, 2013). Hence we expect that:

HP1. A more comprehensive policy mix positively influences innovation performance in EE technologies.

However, the positive impact of *comprehensiveness* may be somewhat reduced if an excessive number of different policies is settled. Trade-offs that are detrimental to the innovation system (e.g., a perception from economic agents of increasing costs in being compliant with different regulatory frameworks, the dispersion of economic resources across small and ineffective public support interventions, the greater likelihood of potential conflicts in final objectives of different tools), can emerge when a disproportionate variety of policy tools are jointly implemented. This may lead to instrument mix *inconsistency,* which is related to the presence of negative interactions and contradictions between different instruments (del Río, 2009b). As stressed by Arundel and Kemp (2009), when the portfolio of policy options is unclear or too detailed, it may also act as a barrier to innovation. This prompts us to formulate the following research hypothesis:

HP2. An excessive variety of policy tools may lead to an instrument mix that is inconsistent and over-dispersed, resulting in negative effects for innovation dynamics in EE technologies.

The different, simultaneous instruments forming the policy setting should also be balanced in terms of the intensity with which different tools are implemented (Kemp and Pontoglio, 2011). For instance, selected scientific contributions claim that the public financing of demand-pull measures aimed at stimulating the deployment of renewable technologies has been disproportionate with investments in R&D policies (Frondel *et al*., 2008; Laleman and Albrecht, 2014; Nemet, 2009). An unbalanced structure of public budgets favouring specific policies may result in a strong orientation of the policy framework that can indeed produce serious consequences in terms of technological and environmental achievements and in terms of a reduced variety of alternative technologies, leading to a possible lock-in effect in inferior technologies (Costantini and Crespi, 2013; Hoppmann *et al*., 2013).

The use of a well-balanced set of different policies may help to stimulate innovation efforts towards both exploitation or exploration activities (Costantini *et al*., 2015). Moreover, the balanced availability of public resources and policy intervention on an array of different instruments may signal a more stable commitment and long-term strategic view, explicitly aimed at achieving synergies between the different policy elements. In this context, the whole innovation system may positively react to lower uncertainty and reduced risk perception (del Río, 2009a; Schmidt *et al*., 2012). Accordingly, we hypothesize that:

HP3. A more balanced policy mix, *ceteris paribus*, has a positive influence on innovation dynamics in EE (internal balance).

Finally, as previously discussed, decisions and policy strategies adopted by other countries are likely to influence internal innovation performance. The issue addressed here is if and to what extent the relation between domestic and foreign policy setting influences countries' innovation patterns. In particular, we expect that the higher the alignment of the domestic policy framework with those adopted by foreign countries (*external balance*), the higher the potential synergies between policy and innovation efforts between the domestic sector and those of other countries. Accordingly, we can hypothesize that:

HP4. The higher the balance of the domestic policy mix with the policy setting adopted by other countries (external balance), the higher the capacity of domestic policy strategy to foster innovation in EE.

3.2 The econometric model

Building on the reviewed literature on the drivers of eco-innovation, the proposed empirical analysis aims to evaluate the impact of policy mix characteristics on the generation of new technologies in the energy efficiency sector by controlling for the different forces able to shape innovation dynamics in the considered sector.

The linear econometric model to be estimated is as follows:

$$\begin{aligned} Y_{i,t} = \alpha_i + \beta_o + \beta_1(EEPol_{i,t-p}) + \beta_2(IntPolMix_{i,t-p}) + \beta_3(ExtPolMix_{i,t-p}) + \\ + \beta_4(InnSys_{i,t-p}) + \beta_5(EneSys_{i,t-p}) + \varepsilon_{i,t} \end{aligned} \tag{1}$$

where $Y_{i,t}$ indicates the innovation performance measure in the EE residential sector, i=1,…,N indexes countries (23 OECD), t=1990,…,2010 indexes time, α_i are country-specific unobserved time invariant effects, p stands for eventual lag structure, and $\varepsilon_{i,t}$ are stochastic errors.

In order to test our hypotheses and account for different factors influencing innovation activities in the sector under scrutiny, five specific groups of variables have been considered representing respectively: the EE domestic policy setting($EEPol$), the range of different characteristics of the EE domestic policy mix ($IntPolMix$), the relationship between the domestic and foreign policy mix ($ExtPolMix$); the national innovation system ($InnSys$), and, finally, the national energy system ($EneSys$).

3.3 The dependent variable

Measuring eco-innovation is not an easy task and a consensus on which is the most coherent and comprehensive method for measuring it has not yet been found. Surveys based on questionnaires capture a wide range of firms' strategies (del Río González, 2005; Frondel *et al.*, 2008; Horbach *et al.*, 2013; Kesidou and Demirel, 2012; Lanoie *et al.*, 2011; Oltra *et al.*, 2010; Wagner, 2007), but they mostly provide qualitative measures of firms' eco-innovation strategies and may be prone to misleading interpretations by surveyed people. Specific expenditures on R&D can be considered a good proxy of innovation activities, but these are rarely available for the private sector when specific technological domains are under scrutiny. On the other hand, patents represent a viable alternative for analysing eco-innovations, being publicly available for rather long time series and providing detailed technological information that allow researchers to conduct rich quantitative analysis. As a consequence, despite their relevant limitations, the use of patent data is widespread in the economics of innovation literature (Archibugi and Pianta, 1996; Arundel and Kabla, 1998; Cohen *et al.*, 2000; Griliches, 1990; Hall *et al.*, 2005; Jaffe and Trajtemberg, 2004; Lanjouw *et al.*, 1998; Lanjouw and Schankerman 2004; Malerba and Orsenigo, 1996; Oltra *et al.*, 2010; Pavitt, 1984; van Pottelsberghe *et al.*, 2001; van Zeebroeck *et al.*, 2006), with a large part of scientific contributions analysing eco-innovation dynamics and focusing on patent-based analysis.

In this work, innovation in the EE domain is represented by the count of patent applications filed at EPO by 23 OECD countries over the period 1990-2010.[2] Despite the extensive work on defining relevant patent classes related to eco-innovation, some specific domains still remain poorly investigated. In the case of EE technologies, standard international patent classification tools only partially and roughly represent the whole range of sub-domains characterizing such a complex field. The patent database here adopted allows the Y02 Cooperative Patent Classification (CPC)[3] based on patent classes for green technologies, which recently incorporated energy efficiency technologies for the residential sector, to be integrated with the specific work carried out by Noailly and Batrakova (2010) mapping EE technologies in the building sub-sector, and the detailed analysis on the sub-sector of electrical appliances developed by Costantini *et al*. (2014b). A complete list of keywords and patent classes used for mapping this technological domain is provided in the Appendix, Tables A1a-A1b.

The selected patents applied to EPO are classified by application date and assigned to the applicant's country. When multiple assignee countries are present for a single patent, we have assigned a proportion of the considered patent to each country on the basis of the number of assignees for each country. Since econometric models for count data work with integer values, we have approximated all count data to the closest integer values. We are aware that several studies have tried to analyse innovation dynamics by also controlling for patent quality (Hall *et al.*, 2005; Jaffe and Trajtenberg, 2004; Popp, 2002). In this respect, two general issues are considered here. First, given that EPO applications are more expensive than applications to national patent offices, inventors typically apply to the EPO if they have strong expectations in terms of economic exploitation of the invention. Hence, for the purpose of this paper, we chose EPO data instead of single national patent offices because the difference in costs provides a quality hurdle which reduces applications for low-value inventions (de Rassenfosse and van Pottelsberghe de la Potterie, 2013; EPO, 1994). While the European market is significant, some bias toward applications from European inventors is still expected. In the empirical analysis undertaken in this study, this bias is addressed through the

[2] Austria, Australia, Belgium, Canada, Switzerland, Germany, Denmark, Spain, Finland, France, United Kingdom, Greece, Ireland, Italy, Japan, Korea, Luxembourg, Netherland, Norway, New Zealand, Portugal, Sweden, United States.
[3] The Cooperative Patent Classification, as developed by the United States Patent and Trademark Office (USPTO), classifies patents into nine sections, A-H and Y, which in turn are sub-divided into classes, sub-classes, groups and sub-groups.

inclusion of country fixed effects. Second, following Squicciarini *et al*. (2013), we performed robustness checks by testing our models on a count indicator based on forward citations in the five years after their publication using the information contained in the OECD EPO Indicators Database.[4]

3.4 The independent variables

3.4.1 Mapping the EE domestic policy setting

In this work, we propose a specific effort to map public policies in the field of energy efficiency since there are a large number of different, overlapping measures. In order to empirically test our research hypotheses on the characteristics of the policy mix, we collected information on three policy domains: i) quantitative demand-pull policies; ii) quantitative supply-push policies; iii) qualitative measures of different instruments based on their different application (regulatory/compulsory vs. information/voluntary approaches).

With regard to the first policy domain, we consider the impact of energy taxation, as a price-based instrument, on the market price in energy demand for the residential sector.[5] The price effects in spurring innovation have been extensively analysed in economics, dating back to the seminal work by Hicks (1932) who attributed to prices the role of a driving force for more efficient input substitution in which part of this process relies on innovation. The effectiveness of the price-inducement effect in the energy sector, and in particular in energy efficiency, has been tested by different contributions which generally found a significant and positive role of prices in fostering innovation dynamics in more efficient energy technologies (Jaffe and Stavins, 1995; Newell *et al*., 1999; Noailly, 2012; Popp, 2002; Verdolini and Galeotti, 2011). Since we are interested in capturing the role of public policy in affecting residential end-use energy prices, we test an extended price-induced mechanism in a price-tax bundle, calculated as the ratio between the energy taxation levy on the total cost of energy consumption (by applying agent prices). In order to consider different energy commodities commonly used in the residential sector, we weight energy prices by consumptions related to each specific source as follows:

$$Tax\_bundle_{i,t} = \frac{\sum_{n=1}^{3} \left(tax_{i,t}^{n} \cdot ener\_cons_{i,t}^{n}\right)}{\sum_{n=1}^{3} \left(price_{i,t}^{n} \cdot ener\_cons_{i,t}^{n}\right)} \tag{2}$$

where n indexes the energy commodity (diesel, electricity and natural gas), whereas i and t refer to

[4] The empirical results obtained by applying a citation-based patent measure largely confirm those obtained by adopting a simple patent count indicator as the dependent variable. In the following sections, we report econometric results based on this latter innovation measure since results based on forward citation measures can be biased due to the truncation problem. For the sake of simplicity, we have only reported results for the simple patent count variables in the text, but all results based on citation patent counts are available upon request from the authors.

[5] Due to data constraints, different forms of demand-pull policies such as command and control instruments are scrutinized in the qualitative domain.

countries and time, respectively. Price and tax rates are taken by IEA Energy Prices and Taxes Statistics (IEA, 2012a), while data on energy consumption are taken by IEA Energy Balance Statistics (IEA, 2012b). All data strictly refer to the residential sector.

The second policy domain, quantitative supply-push instruments, is represented here by a technology-push tool, given by the ratio between public R&D efforts in EE and the total public R&D expenditures in the energy sector (all expressed in million US$ at 2010 prices) taken from IEA Technology Statistics (IEA, 2013a, online database) as:

$$RD_{EE}Ratio_{i,t} = \frac{RD_{EE,i,t}}{RD_{TOTEN,i,t}} \quad (3)$$

This allows us to consider the specific objective of fostering technological innovation in energy efficiency in relation to the whole effort devoted to improving the energy system. This relative measure is needed to account for those countries with a large energy system where monetary values for R&D in energy efficiency may be high in absolute terms but relatively low compared with overall investments in the energy system.[6]

The third policy domain is empirically represented by a range of qualitative instruments aimed at stimulating energy efficiency in the residential sector (see Table 1). This wide set of policies has been mapped by working on the IEA Energy Efficiency Policy and Measures Database (IEA, 2013b) that provides comprehensive up-to-date information on EE policies in seven sectors (buildings, commercial/industrial equipment, energy utilities, industry, lighting, residential appliances and transport) and on specific policy measures across these sectors in OECD countries. Public regulations can be considered on the basis of various criteria (e.g. type of measure, target audience, effective enforcement year, jurisdiction, policy status). Policies still in force or ended during the 1990-2010 period are included in the analysis. In order to exclusively capture residential-related EE policies, public regulations are selected according to the main residential target audiences (namely buildings, lighting and electrical appliances).

The EE policies for the 23 OECD countries considered here are mapped and, for each policy type, a discrete stock variable is calculated as the cumulative number of policy instruments in force at time t in country i, as follows:

$$KPOL_{i,t}^{q} = \sum_{s=1}^{t} (POL_{i,s}^{q}) \quad (4)$$

where $q \in [1,2,\ldots,6]$ represents the six policy instrument types as specified in Table 1. This modelling

[6] The choice of representing the quantitative supply-push policy domain by adopting this technology-side measure is again driven by data availability.

choice allows the whole range of policies still in force at time t in country i, to be considered for each year revealing not only a simple impulse given by the existence or not of EE policies, but also a sort of qualification of the intensity and dynamics of the policy setting.

Table 1– Policy types and instruments for the qualitative domain

Policy Type	Instrument
Economic Instruments	Direct investment Fiscal/Financial incentives Market-based instruments
Information and Education	Advice/Aid in implementation Information provision Performance label Professional training and qualification
Policy Support	Institutional creation Strategic planning
Regulatory Instruments	Auditing Codes and standards Monitoring schemes Obligation schemes Other mandatory requirements
Research, Development and Deployment (RD&D)	Demonstration projects Research programmes
Voluntary Approaches	Negotiated agreements Public voluntary schemes Unilateral commitments

Source: IEA (2013b)

3.4.2 The characteristics of the domestic policy mix

In order to test our hypotheses on the effects of the selected policy mix characteristics, we calculate specific indicators that should allow us to capture the qualitative dimensions we aim to address. In this way, the role played by single instruments can be disentangled from the specific influence exerted by a combination of these instruments.

In particular, the *comprehensiveness* of the policy mix (HP1) is measured by constructing an aggregate stock of total policies for EE given by the sum of the six policy type stocks as given by eq. (5):

$$POL_{Tot_{i,t}} = \sum_{q=1}^{6} \left(KPOL_{i,t}^{q}\right) \tag{5}$$

The analysis of the effects of policy mix *inconsistency* (HP2) is carried out by including a quadratic term of eq. (5) in the econometric specification such as:

$$POL_{Incons_{i,t}} = \left(\sum_{q=1}^{6} \left(KPOL_{i,t}^{q} \right) \right)^{2} \tag{6}$$

The inclusion of this variable in the model allows us to capture eventual non-linear effects. In particular, we can test the existence of a threshold level beyond which the variety of policy instruments contemporaneously implemented becomes excessive, with an increasing risk of conflicting interactions leading to negative effects in terms of innovation performance.

A similar effect of inconsistency-related issues associated to an over-dispersion of efforts across a wide range of instruments is proxied by adding to the model specification an interaction term between the total policy stock and the inverse of the Herfindahl-Hirschman concentration index built on the number of different instruments by which the policy stock is formed:

$$POL_{Dispers_{i,t}} = \sum_{q=1}^{6} \left(KPOL_{i,t}^{q} \right) \cdot \left[1 \Big/ \sum_{q=1}^{6} \left(\frac{KPOL_{i,t}^{q}}{KPOL_{Tot_{i,t}}} \right)^{2} \right] \tag{7}$$

We expect to find a negative sign for this interaction term which would imply that the positive effect associated with increasing comprehensiveness of the policy mix can be reduced due to inconsistency problems when the different policy instruments are dispersed in a wide range of policy domains.

A further characteristic of the policy mix to be measured and investigated is related to the *internal balance* of the whole policy setting. According to HP3, we expect that a more balanced intensity of policy effort in the three policy domains we are able to measure positively affects innovation dynamics in EE technologies. On the contrary, a lower degree of policy balance corresponds to a policy mix composed of a dominant instrument, while all the other policy tools are used at a lower or null degree.

To give an example, if a national government decides to impose a high energy tax on electricity consumption, we have a corresponding high level of the price-tax bundle measure. If the government does not implement a simultaneous effort in terms of R&D expenditures in energy efficiency and other complementary measures such as, for instance, regulatory mandates in terms of energy-efficient electrical devices, the final result of the policy mix will be an increase in energy prices without a parallel enhancement of domestic technological capacities in energy efficiency, so as to reduce the overall cost for society of reaching the efficiency goals.

In order to quantify this effect, we first computed a similarity index between couples of policy instrument domains. The empirical formulation of this measure is adapted from the contributions by Frenken *et al*. (2007) and Los and Timmer (2005) for the cognitive proximity matrix required to assess the technological relatedness. Accordingly, our measure of policy relatedness is as follows:

$$POL_{Bal}{}_{i,t}^{d} = \left[\frac{\left| POL_{dom}{}_{i,t}^{f} - POL_{dom}{}_{i,t}^{g} \right|}{\sqrt[2]{POL_{dom}{}_{i,t}^{f} + POL_{dom}{}_{i,t}^{g}}} \right]^{-1} \qquad \forall f \neq g \tag{8}$$

where $POL_{dom}{}_{i,t}^{f,g} \in \left[Tax\_bundle_{i,t}, RD_{EE}Ratio_{i,t}, POL_{Tot_{i,t}} \right]$ represents the three domains, namely quantitative demand-pull, quantitative technology-push and qualitative measures, and $d = 3$ represents the number of potential couple of similarity between the three policy domains.

In order to standardize the three measures, we have calculated the $POL_{Tot_{i,t}}$ variable as a normalized value by computing the ratio $POL_{dom}{}_{i,t}^{POL_{Tot}} = POL_{Tot_{i,t}}/100$. Since $Max\_POL_{Tot_{i,t}} < 100$, the normalized value is equivalent to the standardized value expressed in percentage terms. Recalling that both $Tax\_bundle_{i,t}$ and $RD_{EE}Ratio_{i,t}$ are expressed in percentage terms, the three policy domains could be treated in the following indices representing the policy mix characteristics.

The three similarity indices obtained by eq. (8) can be synthesized in a unique measure of internal policy balance as the inverse of the standard deviation of the three measures:

$$Tot\_POL_{Bal\,i,t} = \sqrt{\frac{\sum_{d=1}^{3} \left(POL_{Bal}{}_{i,t}^{d} - \frac{\sum_{d=1}^{3} POL_{Bal}{}_{i,t}^{d}}{3} \right)^{2}}{3}}^{\,-1} \tag{9}$$

The closer the similarity between each couple of policy domains, the greater the coherence between them, and the lower the standard deviation among the three couple-based similarity measures, the higher the global balance across all the policy spheres considered here.

3.4.3 The interaction of the domestic policy mix with external policies

Building on previous analyses, we account for the role of policy spillovers defined here as the policy strength adopted by foreign countries weighted by the bilateral export flows in energy intensive manufacturing sectors $X_{ir,t}$ from country i to country r taken from UN-COMTRADE database (see Table A2 for a list of classes and codes) for each policy domain as follows:[7]

$$POL\_Spill_{i,t}^{f} = \sum_{r=1}^{N} X_{ir,t} \cdot POL_{dom}{}_{r,t}^{f} \;\; \forall r \neq i \;\; N = 22 \tag{10}$$

[7] Export flows have been taken from the UN-COMTRADE database (see Table A1).

At a general level, an overall policy spillover effect is then computed by summing all spillovers related to each domain as follows:

$$Tot\_POL\_Spill_{i,t} = \sum_{r=1}^{N} X_{ir,t} \cdot \sum_{f=1}^{3} POL_{dom}{}_{r,t}^{f} \;\; \forall r \neq i \;\; N = 22 \tag{11}$$

In this paper, we are mainly interested in understanding to what extent the foreign policy setting influences the capacity of the domestic policy mix to enhance innovation dynamics. In particular, according to HP4, we aim to evaluate if and to what extent a greater balance between the domestic and the external policy strategy reinforces the inducement effect on innovation dynamics produced by domestic policies. For this purpose, the *external balance* is measured by constructing an indicator based on the co-existence of similar policy efforts in force at time t for country i compared with all other countries (r) for each policy domain (*f*).

The first step involves calculating a bilateral single policy domain similarity index by applying a similarity formula as follows:

$$Bil\_POL_{Bal}{}_{ir,t}^{f} = \left[\left(\frac{\left| POL_{dom}{}_{i,t}^{f} - POL_{dom}{}_{r,t}^{f} \right|}{\sqrt[2]{POL_{dom}{}_{i,t}^{f} + POL_{dom}{}_{r,t}^{f}}} \right)^{-1} \right] \forall r \neq i \; N = 22 \tag{12}$$

This index measures the similarity between the strength of each policy domain in a given country compared with the strength of the same policy domain implemented by every other country. It is worth mentioning that this formulation allows several features to be considered simultaneously. The index value increases if, given a fixed level of the domestic and foreign policy domain, the domestic and foreign policy domains are more similar. At the same time, given a certain degree of similarity, the value increases with the domestic and the foreign policy effort. This last feature ensures both the role of the balance of the domestic policy with the external one and the influence exerted by external policy design in the form of a spillover effect to be considered. Indeed, the value of similarity, *ceteris paribus*, grows with the foreign policy level.

We then construct an aggregate measure of external balance for each single policy domain by adopting as a weighting criterion the value of export flows in energy intensive commodities from each reporting partner *i* towards each partner *r* $X_{ir,t}$:

$$WExt\_POL_{Bal}{}_{i,t}^{f} = \sum_{r=1}^{N} \left(Bil\_POL_{Bal}{}_{ir,t}^{f} \cdot X_{ir,t} \right) \; \forall r \neq i \; N = 22 \tag{13}$$

Finally, we also calculate an overall measure of policy mix external balance by considering all policy domains, applying the same criterion as developed for the internal balance as eq. (9), thus obtaining a Total Weighted External Policy Balance indicator as follows:

$$Tot_{Ext_{POL_{Bal\,i,t}}} = \sum_{r=1}^{N} \left(\sqrt{\frac{\sum_{f=1}^{3} \left(Bil_{POL_{Bal\,ir,t}}^{f} - \frac{\sum_{f=1}^{3} Bil_{POL_{Bal\,ir,t}}^{f}}{3} \right)^{2}}{3}}^{\,-1} \cdot X_{ir,t} \right) \forall r \neq i \; N = 22 \qquad (14)$$

Given the influence exerted by domestic tools *per se*, we expect that the higher the balance of the domestic policies with the global policy setting is, the higher the capacity of the internal policy setting to foster innovation. Moreover, given a certain degree of similarity, the influence of the external balance increases with an additional spillover effect driven by larger foreign policy efforts.

3.4.4 Control variables

In order to disentangle the effects of EE policies and combinations of them in policy mixes, the econometric analysis accounts for two main drivers of eco-innovation in energy technologies identified by previous literature, i.e. the level of national technological capabilities and the structure of the energy system.

In this study, we measure the effort and capability to innovate at country level by computing a knowledge stock based on national gross expenditure in R&D (GERD) taken from OECD Main Science and Technology Indicators (OECD, 2013). Technological knowledge is supposed to operate cumulatively, thus it can be summed over time. However, knowledge capital is also subject to deterioration as it becomes obsolete (Evenson, 2002) and should be discounted to account for this effect. The literature suggests a yearly knowledge depreciation rate ranging between 5 and 30 per cent (Benkard, 2000; Gallagher *et al*., 2012; Hall, 2007, Nemet, 2009). We applied an average decay rate of 15 per cent[8] to the Perpetual Inventory Method suggested by OECD (2009) as follows:

$$Stock_{R\&D} = \sum_{s=0}^{t} \left\{ RD_{i,s} \cdot e^{[-\gamma(t-s)]} \right\} \qquad (15)$$

where γ indicates the discount rate, i indexes countries and t, s indicate the index time. Current values for GERD have been transformed into constant 2010 US$. As additional controls, we also considered

[8] As a robustness check, we also tested different decay rates, namely 10 and 20 per cent. Results in Tables 2-4 are based on a 15 per cent decay rate, and results obtained by applying different rates are quite similar to those reported in the text. Full details on robustness checks are available upon request.

two alternative measures proxying the quality of innovation systems given by: i) the stock of public R&D efforts in EE, provided by the IEA R&D Energy Statistics online database, by applying eq. (15) to R&D in EE annual flows (current values for R&D in EE were converted to constant 2010 US$); ii) the total number of patents applied by different countries to EPO (with the exclusion of specific EE patents), given by the PATSTAT online database.

Finally, considering that EE performances can be affected by the characteristics of the energy system (for instance, the lack of energy production in a given country may induce a higher level of generation and adoption of EE technologies able to counterbalance the suboptimal supply of energy), we synthesize in a unique variable a set of information on the characteristics of the energy system. To do this, we first calculated the level of energy intensity to include a measure of the overall efficiency of a system. According to Patterson (1996), there are different indicators for assessing the aggregated level of intensity in the energy system from which we chose the ratio of energy consumption in the residential sector divided by the level of population.[9] We then computed a measure of the electricity production from internal sources based on OECD Energy Balances, based on the availability of domestic sources (nuclear energy, renewables, and fossil fuels extracted in the national borders) in relation to the total energy supply (both domestic and imported). Hence, a final variable is obtained through the interaction between these two measures. This can be interpreted as follows: given a certain amount of energy intensity (consumption per inhabitant), the larger the quantity of domestically-produced energy, the lower the domestic energy price (given by supply abundance), *ceteris paribus,* the lesser the innovation inducement effect considering the weaker impulse given to firms for enlarging the domestic market of EE technologies.[10]

3.5. The econometric strategy

The use of patent data as proxies of the innovative activity implies that we have to deal with count variables, that is, variables with non-negative integer values. Econometric models specifically designed for this kind of variable are the Poisson Regression Model (PRM) and the Negative Binomial Regression Model (NBRM). The PRM is the natural starting point for an analysis of count data but it may be biased by an excess in zeros and an overdispersion problem. In many applications, the model underestimates the probability of a zero count and low counts in general.[11] In addition, the equidispersion assumption of the Poisson model, the equality of the conditional mean and the conditional variance is commonly violated. Real variables are often overdispersed, that is, the variance exceeds the mean. The major disadvantage in the presence of overdispersion is that estimates are inefficient with the standard errors biased downward, resulting in spuriously large z-values and small

[9] The other standard energy intensity measure is given by the ratio between energy consumption and GDP, but this is more suitable when industrial sectors or the whole economy are under scrutiny.
[10] For an overview of all variables and data sources, see the Appendix, Tables A2-A3-A4a,b.
[11] Alternative methods are designed for variables with excessive zeros (Zero-inflated negative binomial regression, Hurdle model, etc.). See Cameron and Trivedi (2009) for a more comprehensive discussion.

p-values (Cameron and Trivedi, 1986). In these cases, the NBRM, which addresses the failure of the PRM by introducing unobserved heterogeneity across the Poisson means, could be used.

Given that our dependent variables are strongly overdispersed and do not have an excessive number of zeros (see main statistics for the dependent variable reported in Table A4a in the Appendix), a fixed effects NBRM model is used to estimate eq. (1).[12] According to the specification proposed by Hausman *et al*. (1984), we model the number of patents in one year for each country as a Negative Binomial process, since in our dataset, the presence of zeros in the dependent variable is negligible (equal to 20 on a total number of observation of 483) while there is strong overdispersion.[13]

Finally, in order to account for unobservable country-specific heterogeneity, we rely on the fixed effects estimator by conditioning the probability of the counts for each group on the sum of the counts for the group.[14] The maximum likelihood method is used to estimate the model parameters.

When looking at temporal structure, it is worth mentioning that all explanatory variables are treated with a potential number of lags equal to p. This is quite a common choice in the literature where the dependent variable is represented by an innovation output measure. This modelling choice also reduces potential endogeneity issues related to regressors such as, for instance, innovation input or policy variables which may be endogenously linked to the dependent variable.

In order to test the validity of alternative lag structures, we have performed a Bayesian information criterion (BIC) applied to model in eq. (1) testing for p assuming value 1, 2, 3. Since the penalty term for the number of parameters in the model is larger in BIC than in AIC, the first one is to be preferred as a more stringent overfitting model test.[15] The resulting temporal structure from BIC values is characterized by one year lag. This empirical result is consistent with existing contributions (see Johnstone *et al*., 2010, among others). Moreover, from a conceptual point of view, energy efficiency policy variables over this medium term are rather stable or growing slightly because they respond to a long run commitment in policy design and it is therefore difficult to estimate complicated lag structures.[16]

The inclusion of policy variables in the regressors may present econometric problems related to potential bias in estimations due to endogeneity. At the theoretical level, this arises if a mutual causality between policy and innovation exists, since technological progress may ensure increased

[12] The Likelihood-ratio test on the overdispersion parameter comparing the PRM with the NBRM applied to each model presents values associated with p-values equal to zero. This is strong evidence of overdispersion, then the NBRM is preferred to the PRM. As an example, the LR test for Column (1) in Table 3 is 9,517 (p-value =0.000).

[13] The NBRM can be specified with two different variants. The most commonly used is the negative binomial mean-dispersion model that assumes a quadratic variance specification. The alternative is the negative binomial constant-dispersion model where the dispersion is constant for all observations. Given that the quadratic variance specification is a very good approximation in many cases of overdispersed data, we use the former variant of the model. See Cameron and Trivedi (1998) for more details.

[14] Given that fixed effects refer to the distribution of the overdispersion parameter δ_i, the fixed effects negative binomial regression is unusual among fixed effects models and allows estimation of the coefficients of time varying regressors. In our model, the Hausman test points out that the fixed effects estimator is more appropriate than the random effects estimator, since it assumes a value equal to 185.64 with p-value =0.000.

[15] Results on BIC for alternative lag structures are available upon request from the authors.

[16] This is also valid for the other explanatory variables, especially those related to innovation capabilities (Hall *et al*., 1986).

competitiveness on the market for a specific technological domain, leading to changes in policy maker decisions that could be more favourable in adopting stringent environmental policies in those fields where technologies are already available. Since the temporal structure with policy variables with temporal lags may not be enough to mitigate potential endogeneity, we also control for this potential bias by implementing a GMM estimator for count variables with endogeneous regressors (Windmeijer, 2006, 2008) applied to eq. (1). The results obtained for the three specifications considering the intensity of policy efforts in the three policy domains here considered $\left(Tax\_bundle_{i,t}, RD_{EE}Ratio_{i,t}, POL_{Tot_{i,t}}\right)$ are reported in the Appendix, Table A6, revealing that the NBRM estimates are robust and not affected by endogeneity issues. Thus, results presented in the following Section are all based on the NBRM estimator.

4. Empirical results

The first part of the empirical analysis refers to the estimation of a baseline model in which the role of policy inducement effects played by domestic policies on the dynamics of EE innovation is tested. This step in the analysis allows us to test this standard policy inducement hypothesis on our novel panel dataset, according to the recent empirical analyses that include several instruments on both the demand and the technological supply sides. Such a test is designed to provide us with a solid empirical base on which to investigate the validity of our specific hypotheses.

Results reported in Table 2 show that for all variables related to the quality of national innovation systems, the associated coefficients result positive and statistically robust, revealing that technological capabilities play a relevant role in shaping innovation activities in the specific domain under scrutiny. In the following specifications, we will use the stock of GERD as representative for the national innovation system, but all results are fully consistent if the two alternative innovation variables are adopted.[17] Results show that controlling for the role of the energy system is also appropriate with our variable representing the internal energy abundance significantly entering the model with the expected negative sign according to the hypothesis that those countries equipped with a relatively more abundant domestic energy supply, ceteris paribus, have a lower propensity to intensify the adoption and diffusion of efficient energy consumption behaviours.

Moving to the analysis of results related to individually tested EE policies, results reported in Table 2 suggest that both demand-pull/price-based effects and technology-push drivers have the capacity to stimulate innovative performance in EE technologies. According to previous findings, the most effective policy instrument is the demand-pull option represented by the energy tax bundle variable, with a coefficient that is more than double in its estimated value compared with the EE R&D variable. In order to test for the role played by the multiple policy types available from the panel dataset, we

[17] Results reported in Tables 2,3,4 are obtained by applying a one-year lag to covariates in order to control for potential endogeneity. The temporal structure has been selected according to robustness checks carried out with the help of a Bayesian Information Criterion (BIC) for three alternative lag structures, namely one, two or three year lag. According to the BIC test, we selected the specification with the lower BIC value, corresponding to the one-year lag temporal structure.

also add each single policy type classified according to Table 1 to the econometric specifications beside the two demand-pull and technology-push quantitative variables.

Results show that the efforts played by analysed countries in settling complementary instruments seem to produce a positive outcome in terms of the innovation inducement effect since all the six policy types turn out to provide additional stimuli to innovation achievements with respect to demand-pull and technology-push instruments proxied by quantitative variables. This result appears to be relevant since it shows the great potential of soft instruments in shaping eco-innovation dynamics, an aspect that is not often addressed by the literature.

When going into detail regarding the different policy types, those with the largest influence are represented by information and education and regulatory approaches. It is worth noting that the six instrument types cannot be jointly tested because of their mutual correlation that would produce statistical bias due to multicollinearity in the econometric estimation (see Tables A5a,b in the Appendix).

The results discussed so far allow us to conclude that the policy inducement effect is confirmed in EE technologies and that both the database and the specified baseline model can represent a reliable empirical environment where the validity of our specific research hypotheses on the innovation impact of the selected policy mix characteristics can be tested.

According to HP1, together with the role played by demand-pull and technology-push instruments, we consider how positive is the role played by a comprehensive set of different instrument types jointly adopted in order to complement the effectiveness of standard tools. Results reported in Table 3 (Column 1) show that a comprehensive policy mix provides a positive impulse to innovate as suggested by the positive and statistically robust coefficient for comprehensiveness indicator here measured as indicated by eq. (5).

Moreover, although a wide range of different policy types has to be considered as a positive element, when the number of instruments becomes so high that it is difficult to ensure their consistency, some negative effects may occur if innovators perceive incoherence and uncertainty in implementing so many different legal mechanisms. This is exactly what data tell us when testing HP2. The quadratic term of the total stock of policy types (as measured by eq. 6) has a negative and statically robust coefficient, revealing that an excessive number of policies negatively influences the propensity to innovate in EE technologies (Column 2).

The variety of different policies simultaneously implemented in the policy mix fosters innovation dynamics up to a threshold level where difficulties in coordination and inconsistency of the policy mix, mainly in terms of potential conflicting effects determined by too many and too pervasive policy instruments, may become relevant.[18] This qualitative feature of the internal policy mix is further investigated by controlling for the role of dispersion of public efforts in an excessive number of

[18] This specific result is not biased by the introduction of the quadratic term in statistical terms since the BIC value for model fitting in Column (2) is lower than that in Column (1), thus emphasising a better fitting when the quadratic term is included.

distinguished instruments. According to the dispersion measure as provided by eq. (7), the positive role played by a comprehensive policy mix is partly reduced if policies are overdispersed across a too large range of alternative types. The negative value for the coefficient associated with dispersion reveals that a coordination failure may be detrimental to innovation dynamics, suggesting that it is not only a matter of implementing a large number of complementary measures that characterize the policy mix, but also how efforts are distributed across different instruments. This aspect should be accounted for when designing a proper, well functioning policy mix.

The quality of the policy mix should also be seen from the point of view of how balanced the different policy domains are in the general setting. In this case, we consider the whole policy mix represented by both quantitative and complementary instruments, as expressed by eq. (9). According to HP3, the different, simultaneous instruments forming the policy setting should also be balanced in terms of the intensity with which different tools are implemented.

Table 2 - Inducement effect of domestic policy instruments (HP1)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Stock of GERI	0.618***			0.693***	0.762***	0.684***	0.683***	0.693***	0.638***	0.739***	0.750***
	(13.28)			(13.77)	(15.91)	(13.24)	(13.26)	(13.40)	(12.09)	(14.84)	(14.90)
Stock of RD in El		0.403***									
		(14.70)									
EPO pat. per cap			0.465***								
			(13.25)								
Energy tax (demand-pull				0.523***		0.359***	0.310***	0.374***	0.358***	0.381***	0.342***
				(6.56)		(4.33)	(3.85)	(4.58)	(4.30)	(4.68)	(4.27)
RD in EE (technology-push					0.242***	0.087***	0.103***	0.146***	0.096***	0.153***	0.168***
					(8.31)	(2.60)	(3.14)	(4.38)	(2.78)	(4.67)	(5.24)
Econ. instrument						0.203***					
						(7.19)					
Info. & edu							0.226***				
							(7.46)				
Policy suppor								0.190***			
								(5.24)			
Reg. instrument									0.241***		
									(7.49)		
RD&D suppor										0.191***	
										(4.67)	
Vol. app											0.171***
											(4.11)
Energy intensit	-0.267***	0.138**	-0.425***	-0.275***	-0.134*	-0.210***	-0.188***	-0.172**	-0.216***	-0.186***	-0.169**
	(-3.95)	(1.97)	(-5.44)	(-4.19)	(-1.95)	(-3.09)	(-2.74)	(-2.52)	(-3.13)	(-2.72)	(-2.49)
Constar	-7.478***	-0.011	2.867***	-7.620***	-10.178***	-7.869***	-8.040***	-8.254***	-7.218***	-9.013***	-9.286***
	(-11.10)	(-0.06)	(13.72)	(-10.26)	(-14.41)	(-9.60)	(-9.97)	(-10.22)	(-8.64)	(-11.64)	(-12.05)
N	460	460	460	460	460	460	460	460	460	460	460
chi2	177.80	225.38	176.82	223.08	322.43	571.05	550.20	468.82	514.60	446.75	429.68

z statistics in parentheses
* *p*< 0.1, ** *p*< 0.05, *** *p*< 0.01

Table 3 - Comprehensiveness, inconsistency, dispersion and internal balance

	(1)	(2)	(3)	(4)	(5)
Stock of GERD	0.633***	0.666***	0.679***	0.624***	0.664***
	(11.99)	(12.37)	(12.57)	(11.75)	(12.36)
Energy tax (demand-pull)	0.322***	0.261***	0.299***	0.326***	0.263***
	(3.94)	(3.17)	(3.70)	(3.98)	(3.23)
RD in EE (technology-push)	0.056*	0.072**	0.072**	0.037	0.053
	(1.69)	(2.24)	(2.22)	(1.03)	(1.54)
EE policy stock (comprehensiveness)	0.206***	0.418***	0.444***	0.217***	0.430***
	(9.02)	(7.91)	(6.90)	(9.06)	(8.17)
EE policy stock sq. (inconsistency)		-0.070***			-0.071***
		(-4.49)			(-4.59)
EE policy stock Herf-Hirsch (dispersion)			-0.156***		
			(-3.97)		
Internal Policy Balance				0.052*	0.054**
				(1.88)	(2.02)
Energy intensity	-0.217***	-0.227***	-0.240***	-0.224***	-0.228***
	(-3.13)	(-3.19)	(-3.45)	(-3.22)	(-3.21)
Year dummy 2000	0.146**	0.111	0.117*	0.140*	0.105
	(2.05)	(1.62)	(1.71)	(1.95)	(1.53)
Constant	-7.032***	-7.552***	-7.769***	-6.914***	-7.540***
	(-8.40)	(-8.87)	(-9.12)	(-8.26)	(-8.95)
N	460	460	460	460	460
chi2	625.208	612.905	633.680	621.173	607.557

z statistics in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

As an example, an unbalanced structure of public efforts mostly favouring technology-push policies without a proper set of demand-pull and other complementary instruments influencing consumers' behaviour, may convince innovative investors that there is an inadequate demand for new technologies, reducing profit expectation and thus lowering the propensity to innovate. On the contrary, an excessive set of complementary measures mainly aiming at changing consumers' conduct without providing enough resources to fuel technological progress may lead to increasing technology imports from abroad without developing a domestic capacity of generating the new technologies demanded by consumers. As showed by results in Columns (4)-(5) in Table 3, an unbalanced internal policy mix negatively influences innovation efforts in EE technologies, suggesting that the overall policy setting should be designed by taking into account the relative strength of policy instruments. The balanced distribution of economic resources and policy efforts across different instruments, in fact, may reduce the uncertainty associated with the stability over time of a single instrument, thus increasing the perception of a long-term strategic view behind the implemented policy mix which may lead to a positive creative reaction of the whole innovation system.

Finally, together with the role played by the characteristics of the domestic policy mix, the policies adopted by foreign countries may also influence innovation patterns both by interacting with the internal policy mix and by directly changing innovation behaviour at the domestic level. As shown in Column (1) in Table 4, there is clear and robust evidence that the adoption of a general policy setting oriented toward EE in the residential sector by other countries pushes domestic innovation capacity.

Table 4 - External balance and spillovers

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Stock of GERD	0.427***	0.536***	0.535***	0.501***	0.611***	0.651***	0.660***	0.577***
	(6.29)	(7.42)	(7.74)	(8.14)	(10.86)	(11.68)	(11.69)	(9.57)
Energy tax (demand-pull)	0.077	0.175**	0.166**	0.116	0.305***	0.274***	0.264***	0.258***
	(0.92)	(2.04)	(1.99)	(1.39)	(3.66)	(3.28)	(3.19)	(3.12)
RD in EE (technology-push)	0.108***	0.076**	0.075**	0.121***	0.078**	0.074**	0.071**	0.087***
	(3.57)	(2.42)	(2.45)	(3.97)	(2.40)	(2.29)	(2.22)	(2.64)
EE policy stock (comprehensiveness)	0.223***	0.372***	0.350***	0.197***	0.336***	0.409***	0.417***	0.307***
	(4.09)	(6.81)	(6.43)	(3.60)	(5.87)	(7.63)	(7.86)	(5.01)
EE policy stock sq. (inconsistency)	-0.059***	-0.064***	-0.060***	-0.065***	-0.053***	-0.068***	-0.070***	-0.050***
	(-3.93)	(-4.06)	(-3.89)	(-4.28)	(-3.23)	(-4.30)	(-4.46)	(-2.93)
General policy spillovers	0.314***							
	(8.05)							
Energy tax spillovers		0.194***						
		(2.91)						
RD in EE spillovers			0.212***					
			(3.63)					
EE policy stock spillovers				0.167***				
				(8.72)				
External Policy Balance					0.049***			
					(3.55)			
Energy tax External Balance						0.019		
						(1.08)		
RD in EE External Balance							0.005	
							(0.37)	
EE policy stock External Balance								0.085***
								(3.56)
Energy intensity	-0.253***	-0.231***	-0.275***	-0.225***	-0.224***	-0.234***	-0.228***	-0.268***
	(-3.41)	(-3.27)	(-3.8)	(-2.96)	(-3.17)	(-3.29)	(-3.20)	(-3.64)
Constant	-8.712***	-8.804***	-8.969***	-7.273***	-7.526***	-7.698***	-7.563***	-7.636***
	(-10.30)	(-9.31)	(-9.63)	(-8.47)	(-9.11)	(-8.93)	(-8.90)	(-9.33)
N	460	460	460	460	460	460	460	460
Chi2	738.394	643.777	665.821	743.245	640.367	614.922	613.759	635.872

z statistics in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Policies implemented by foreign countries create the conditions for an enlarged demand for energy-efficient technologies that may be satisfied by the production of new technologies in the domestic context. This is more likely if well established export flows of energy-intensive goods link the domestic country to the foreign ones. If the foreign country needs to import more efficient energy-intensive goods in order to be compliant with the internal regulatory setting, this stimulates the domestic innovation activities in order to better satisfy external demand for those goods. The relevance of the external policy setting is confirmed for all the policy domains considered here (Columns 2-4).

In this study, we are specifically interested in understanding how the decisions on the design of the internal policy mix interfere with the external effects of foreign policies. In particular, according to HP4, we want to verify if the coherence of the internal policy mix with the policy mix adopted abroad (external balance) represents an additional element of policy design that positively influences domestic technological dynamics. In this respect, as shown in Column 5 in Table 4, the coefficient associated with the external policy balance indicator (eq. 14) turns out to be positive and significant, suggesting that the global external balance of the domestic policy mix with the foreign ones generates an additional positive effect on innovation activities in EE technologies, driven by external policy spillover effects. This means that in the domain of EE technologies, when the policy mix adopted is well balanced with respect to those implemented by countries importing a high share of energy intensive goods from the analysed country, domestic innovative performance is enhanced by better exploiting the market opportunities created by a strong foreign regulatory framework.

Finally, when the external balance is investigated at the single policy domain level, it is worth noting that a better balance of the domestic demand-pull and technology-push instruments with those adopted abroad does not play a role in fostering EE innovation. On the contrary, the external balance of the stock of qualitative instruments, including regulatory and voluntary tools, is reasonably effective in shaping technological dynamics. This specific empirical outcome is worth mentioning since it is in line with recent theoretic investigations into the critical role of soft instruments. Complementary measures that shape the comprehensiveness of the internal policy mix are more effective in inducing innovation in EE technologies if they are well balanced with the policy mix of the major trading partners in energy intensive goods.

5. Conclusions

This study provides an empirical analysis of the influence of the characteristics of the policy mix on innovation patterns in energy efficiency technologies for the residential sector in 23 OECD countries for the period 1990-2010.

Our analysis shows that different policy types, including the soft instruments represented here by information and education, policy and RD&D support and voluntary approaches, are effective in influencing innovation dynamics in the energy efficiency domain. While the direct impact of individual instruments is confirmed, the analysis of the characteristics of the policy mix allows us to make a step further with regard to existing studies by revealing new insights into how to design an effective combination of different instruments.

First, the empirical analysis shows that a more comprehensive policy mix is able to enhance innovation activities in the domain of EE technologies. However, our results also reveal that the simple addition of an indiscriminate number of simultaneous policy instruments may create inconsistencies. These are associated with coordination problems, mainly in terms of potential conflicting effects determined by the co-existence of too many policy instruments, potentially reducing the innovation inducement capacity of the overall policy effort. In this respect, an implication that arises from our analysis is that an active role by governments in coordinating the complex interaction between different instruments in order to fully exploit its innovation inducement effect is certainly needed.

Second, a more balanced use of the different policy instruments adopted at the domestic level seems to be a good policy strategy to be adopted since, *ceteris paribus*, it has a positive influence on innovation dynamics. When the intensity of policy efforts is not concentrated in just one or few instruments, relevant agents may perceive the overall policy strategy as more stable and characterized by a long-term view. This may lead to the innovation system reacting positively to lower uncertainty and reduced risks.

Third, together with the role played by the characteristics of the domestic policy mix, the policies adopted by foreign countries also influence innovation patterns by interacting with the internal policy mix. Our findings confirm previous evidence on the relevance of policy spillover effects on domestic innovation activities which seem to play a role both in the demand-pull and technology-push dimensions as well as in complementary policy instruments. Moreover, the empirical results highlight that the inducement effects of domestic policies are reinforced when the external balance of the policy mix design is higher. Interestingly, this effect is detected for complementary qualitative instruments which seem to amplify their potential role when they are aligned with similar accompanying policies adopted by other countries.

Considering the complexity of the issue at stake, our analysis does not aim to address all the elements involved and certainly needs complementary studies to increase our understanding of the channels through which policy mix characteristics influence eco-innovation performances. In particular, the examined characteristics, though grounded on previous theoretical contributions, have also been chosen considering the availability of statistical information suitable for a quantitative analysis on a representative sample. Hence, further policy mix characteristics could be explored if other information sources become available. Moreover, in this paper, we do not study policy processes that may explain the evolution but also the impact of policy mixes, and we do not explicitly address the long-term strategic component of policy mix. In this respect, a proper comprehension of the mechanisms linking policy mix design and eco-innovation performances certainly needs the continuous integration of complementary quantitative and qualitative research efforts.

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Appendix

Table A1a – Patent classes by technological domains and keywords

Main domain	Sub-domain	CPC Class	Sub-classes	Keywords
Insulation	Heat Saving	E06B	3/24, 3/64, 3/66, 3/67	
		E06B	3	high perform+ OR insulat+ OR low energy
		C03C	17/00, 17/36	low e
		E06B	3/67F	vacuum
		E06B		aerogel
		E06B	3/20	
		E06B	1/32, 3/26	thermal break
		E04B	1/74, 1/76	
		E04B		Polyurethane OR PUR OR polystyrene OR EPS OR XPS OR heavy gas+ OR pentane OR insulat+
		E04B		Flax OR straw OR (sheep+ AND wool)
		E04F	15/18	
		E04F		Sea shell
		E04D	11	Insulat+
		E04D	11	Green roof
		E04D	11, 9	thatch+
		F16L	59/14	
	Water saving	F24H		Water AND (sav+ OR recover+)
		F16K	1	Water AND (sav+ OR recover+)
		E03C	1	Water AND (sav+ OR recover+)
	Cooling reduction	E04F	10	
		C03		Glass AND (reflect+ OR sunproof OR heat resist+)
		E06B	3	Glass AND (reflect+ OR sunproof OR heat resist+)
		B32B	17	Glass AND (reflect+ OR sunproof OR heat resist+)
High-efficiency boilers	HE-boilers	F23D	14	Low
		F24D	1	
		F24D	3, 17	
		F24H, excluding F24H7		
Heat and cold distribution and CHP	Heating system	F24D	5, 7, 9, 10, 11, 13, 15, 19	
	Storage heaters	F24H	7	
	Heat exchange	F28F	21	
	Cooling	F25B	1, 3, 5, 6, 7, 9, 11, 13, 15, 17	
	Combined heating and refrigeration systems	F25B29		
	Heat pumps	F25B30		
	CHP	X11-C04		
		R24H240/04 (ICO		
Ventilation	Ventilation	F24F	7+	
Solar energy and other RES	Solar energy	F24J	2	
		H01L	31/042, 31/058	
		H02N	6	
	Biomass	F24B		Wood+
	Geothermal	F24J	3	
Building materials	Construction structures	E04B	1	Building+ or house+
	Materials	C09K	5	Building+ or house+
Climate control systems	Temperature control	G05D	23/02	
	Electric heating devices	H05B	1	
Lighting	Lighting	F21S		Not vehicle, not aircraft
		F21K	2	Not vehicle, not aircraft
		H01J	61	Not vehicle, not aircraft
		F21V	7	House or home or building
	LED	H01L	33	Light and LED
		H05B	33	Light and LED

Source: adapted from Noailly and Batrakova (2010)

Table A1b – Patent classes by technological domains and keywords

CPC general Class related to each appliance		Technologies aimed at improving efficiency of home appliances	Description
Refrigerators and freezers	F25D See http://www.cooperativepatentclassification.org/cpc/scheme/F/scheme-F25D.pdf	Y02B 40/32	Motor speed control of compressors or fans
		Y02B 40/32	Thermal insulation
Dish-washers	A47L 15/00 See http://www.cooperativepatentclassification.org/cpc/scheme/A/scheme-A47L.pdf	Y02B 40/42	Motor speed control of pumps
		Y02B 40/44	Heat recovery e.g. of washing water
Washing-machines	D06F (excluding D06F31/00, D06F43/00, D06F47/00, D06F58/12, D06F67/04, D06F71/00, D06F89/00, D06F93/00, D06F95/00 as well as their subgroups). See http://www.cooperativepatentclassification.org/cpc/definition/D/definition-D06F.pdf	Y02B 40/52	Motor speed control of drum or pumps
		Y02B 40/54	Heat recovery, e.g. of washing water
		Y02B 40/56	Optimization of water quantity
		Y02B 40/58	Solar heating

Source: own elaboration based on EPO-PATSTAT

Table A2 – SITC Rev 3 CODE in COMTRADE taken for the aggregate "energy consuming manufacturing sectors plus building sector"

Code	Description	Code	Description
201	Milling, planning and impregnation	287	Other fabricated metal products
202	Panels and boards of wood	291	Machinery for production, use of metal products
203	Builders' carpentry and joinery	292	Other general purpose machinery
204	Wooden containers	295	Other special purpose machinery
205	Other products of wood; articles of	297	Domestic appliances n. e. c.
243	Paints, coatings, printing ink	300	Office machinery and computers
251	Rubber products	311	Electric motors, generators and transport
252	Plastic products	312	Electricity distribution and control
261	Glass and glass products	313	Isolated wire and cable
262	Ceramic goods	314	Accumulators, primary cells
263	Ceramic tiles and flags	315	Lighting equipment
264	Bricks, tiles and construction prod	316	Electrical equipment n. e. c.
265	Cement, lime and plaster	321	Electronic valves and tubes, other
266	Articles of concrete, plaster and cement	322	TV, and radio transmitters, apparatus
267	Cutting, shaping, finishing of stone	323	TV, radio and recording apparatus
268	Other non metallic mineral products	401	Production and distribution of electricity
282	Tanks, reservoirs, central heating	742	Architectural and engineering activity
283	Steam generators		

Table A3 – Variable description and data sources

Variable name	Description	Source
Stock of GERD	Stock of gross RD expenditures eq. (15)	OECD MSTI Indicators
Stock of RD in EE	Stock of public gross RD expenditures in energy efficiency eq. (15	IEA RD Statistics
Pat. EPO per cap.	Number of total patents applied to EPO per capita	OECD PATSTAT, OECD STATS
Energy tax (demand-pull)	Ratio between the energy taxation levy on the total cost of energy consumption as eq. (2)	IEA Energy Prices and Taxes Statistics, IEA OECD Energy Balance Statistics
RD in EE (technology-push)	Ratio between public RD in energy efficiency and public RD in the energy sector as eq. (3)	IEA RD Statistics
Economic instruments	Stock of number of policies in each type (Table 1) as eq. (4)	IEA Energy Efficiency Policy online Database
Info. & Education		
Policy support		
Regulatory instruments		
RD&D support		
Voluntary approaches		
EE policy stock (comprehensiveness)	Sum of all policies as eq. (5)	
EE policy stock sq. (inconsistency)	Square of sum of all policies as eq. (6)	
EE policy stock Herf-Hirsch (dispersion)	Variance across policy types weighted by an Herfindal-Hirschman index as eq. (7)	
Internal balance	Balance across the policy domains as eq. (9)	IEA Energy Prices and Taxes Statistics, IEA OECD Energy Balance Statistics, IEA RD Statistics, IEA Energy Efficiency Policy online Database
General spillovers	Total policy instruments adopted by foreign countries weighted by export flows in energy intensive goods as Table A1a –A1b as eq. (11)	IEA Energy Prices and Taxes Statistics, IEA OECD Energy Balance Statistics, IEA RD Statistics, UN-COMTRADE
Energy tax spillovers	Demand-pull instruments adopted by foreign countries weighted by export flows in energy intensive goods as Table A1a –A1b as eq. (10)	
RD in EE spillovers	Technology-push instruments adopted by foreign countries weighted by export flows in energy intensive goods as Table A1a –A1b as eq. (10)	
EE policy stock spillovers	Total complementary tools adopted by foreign countries weighted by export flows in energy intensive goods as Table A1a –A1b as eq. (10)	
External policy balance	Balance between the domestic policy mix and the policy adopted abroad by OECD trade partners as eq. (14)	
Energy tax external balance	Balance between the domestic demand-pull policy and that adopted abroad by OECD trade partners as eq. (13)	
RD in EE external balance	Balance between the domestic technology-push policy and that adopted abroad by OECD trade partners as eq. (13)	
EE policy stock external balance	Balance between the domestic stock of complementary tools and those adopted abroad by OECD trade partners as eq. (13)	
Energy intensity	Per capita energy consumption fuelled by domestic primary sources	IEA OECD Energy Balance Statistics, OECD STATS

Table A4a – Dependent variables statistics

Variable name	Obs	Mean	Std. Dev.	Min	Max	Var.
Total Patents in EE (depend. var.)	483	114.41	196.25	0	894	38,512
No. of zeros in Total Patents in EE	20					

Table A4b – Independent variables statistics

Variable name	Obs	Mean	Std. Dev.	Min	Max
Stock of GERD	483	15.03	1.72	11.57	19.06
Stock of RD in EE	483	3.95	1.94	-2.32	8.45
EPO pat. per cap.	483	-2.71	2.38	-8.74	2.22
Energy tax (demand-pull)	483	-1.82	0.69	-3.08	-0.49
RD in EE (technology-push)	483	2.62	0.91	-2.17	5.29
Economic instruments	483	0.56	0.80	0	2.94
Info. & Education	483	0.70	0.86	0	3.33
Policy support	483	0.32	0.55	0	2.30
Regulatory instruments	483	0.78	0.80	0	2.77
RD&D support	483	0.19	0.41	0	2.30
Voluntary approaches	483	0.26	0.58	0	2.83
EE policy stock (comprehensiveness)	483	1.16	1.06	0	3.91
EE policy stock sq. (inconsistency)	483	2.47	3.15	0	15.30
EE policy stock Herf-Hirsch (dispersion)	483	1.57	1.69	0	6.91
Internal balance	483	1.32	0.90	-1.85	6.93
General spillovers	481	14.63	1.79	9.45	18.16
Energy tax spillovers	483	15.30	1.57	10.92	18.27
RD in EE spillovers	483	15.04	1.64	10.80	18.35
EE policy stock spillovers	481	13.55	2.49	5.47	18.03
External policy balance	483	19.16	2.28	12.38	25.83
Energy tax external balance	483	19.72	1.93	15.01	26.93
RD in EE external balance	483	19.52	1.96	14.26	26.62
EE policy stock external balance	483	18.52	1.98	12.37	22.84
Energy intensity	483	0.09	1.00	-2.21	2.65

Table A5a – Correlation matrix (values)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
(2)	0.78																						
(3)	0.68	0.63																					
(4)	-0.06	0.07	0.03																				
(5)	-0.25	0.04	-0.18	0.25																			
(6)	0.42	0.37	0.17	-0.12	0.04																		
(7)	0.43	0.37	0.20	-0.17	0.00	0.62																	
(8)	0.42	0.36	0.22	0.02	0.03	0.69	0.71																
(9)	0.37	0.33	0.24	-0.02	0.15	0.60	0.82	0.70															
(10)	0.34	0.27	0.15	-0.14	0.06	0.67	0.57	0.73	0.56														
(11)	0.47	0.42	0.16	-0.18	0.04	0.53	0.72	0.55	0.54	0.53													
(12)	0.46	0.41	0.26	-0.04	0.06	0.79	0.88	0.75	0.90	0.66	0.63												
(13)	0.52	0.47	0.24	-0.14	0.05	0.84	0.88	0.81	0.84	0.76	0.72	0.94											
(14)	0.47	0.42	0.25	-0.06	0.07	0.82	0.89	0.84	0.88	0.75	0.70	0.97	0.97										
(15)	-0.24	-0.05	-0.04	0.35	0.39	-0.13	-0.22	-0.18	-0.13	-0.14	-0.16	-0.14	-0.22	-0.19									
(16)	0.83	0.63	0.67	0.01	-0.13	0.44	0.39	0.42	0.44	0.32	0.30	0.49	0.49	0.49	-0.13								
(17)	0.83	0.62	0.69	0.06	-0.13	0.33	0.22	0.32	0.28	0.21	0.21	0.32	0.35	0.33	-0.10	0.94							
(18)	0.88	0.65	0.69	0.01	-0.16	0.38	0.31	0.34	0.32	0.25	0.28	0.37	0.41	0.39	-0.16	0.96	0.98						
(19)	0.68	0.53	0.56	-0.02	-0.10	0.50	0.50	0.47	0.55	0.39	0.34	0.62	0.57	0.60	-0.11	0.93	0.75	0.80					
(20)	0.70	0.49	0.55	-0.06	-0.15	0.36	0.35	0.35	0.42	0.25	0.29	0.45	0.42	0.43	-0.12	0.86	0.77	0.80	0.85				
(21)	0.70	0.41	0.59	-0.12	-0.20	0.22	0.20	0.23	0.26	0.16	0.19	0.24	0.26	0.25	-0.19	0.77	0.78	0.79	0.65	0.81			
(22)	0.77	0.60	0.59	-0.06	-0.20	0.27	0.26	0.30	0.24	0.22	0.29	0.29	0.33	0.30	-0.18	0.80	0.81	0.84	0.66	0.81	0.70		
(23)	0.76	0.57	0.65	0.04	-0.13	0.43	0.40	0.42	0.49	0.31	0.28	0.54	0.49	0.51	-0.09	0.93	0.85	0.86	0.89	0.89	0.71	0.71	
(24)	0.33	0.10	0.51	-0.10	-0.39	0.01	0.03	0.04	-0.02	0.07	0.08	0.04	0.03	0.05	-0.15	0.26	0.25	0.28	0.22	0.24	0.34	0.23	0.26

Table A5b – Correlation matrix (labels)

Code	Full label	Code	Full label	Code	Full label
(1)	Stock of GERD	(9)	Regulatory instruments	(17)	Energy tax spillovers
(2)	Stock of RD in EE	(10)	RD&D support	(18)	RD in EE spillovers
(3)	EPO pat. per cap.	(11)	Voluntary approaches	(19)	EE policy stock spillovers
(4)	Energy tax (demand-pull)	(12)	EE policy stock (comprehensiveness)	(20)	External policy balance
(5)	RD in EE (technology-push)	(13)	EE policy stock sq. (inconsistency)	(21)	Energy tax external balance
(6)	Economic instruments	(14)	EE policy stock Herf-Hirsch (dispersion)	(22)	RD in EE external balance
(7)	Info. & education	(15)	Internal balance	(23)	EE policy stock external balance
(8)	Policy support	(16)	General spillovers	(24)	Energy intensity

Table A6 – GMM on count variable estimator applied to main models reported in Tables 2-3

	(4) in Table 2	(5) in Table 2	(1) in Table 3[§]
Stock of GERD	1.684***	1.653***	1.157***
	(11.89)	(13.65)	(6.14)
Energy tax (demand-pull)	0.210**		
	(2.18)		
RD in EE (technology-push)		0.154***	
		(4.31)	
EE policy stock (comprehensiveness)			0.157***
			(4.60)
Energy intensity	1.896***	1.629***	2.045***
	(4.31)	(3.73)	(4.16)
N	460	460	460

z statistics in parentheses
* $p< 0.1$, ** $p< 0.05$, *** $p< 0.01$
[§] Column (1) in Table 3 is here replicated with GMM estimation excluding the other policy domains in order to strictly assess the potential endogeneity of each single policy domain.