EXTENDED ABSTRACT

Title: Causality pathways for the eco-innovation phenomenon: a fsQCA analysis

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Abstract:

1. Introduction

New societal demands related to sustainable development have increased the concern and interest in eco-innovation (Hojnik & Ruzzier, 2016). Eco-innovation reduces the negative environmental impact of human activities (Horbach, 2016) while positively affecting societal welfare and national competitiveness, boosting the economy (Porter & van der Linde, 1995; Păcesilă & Ciocoiu, 2017). Hence, eco-innovation can become a crucial national strategy because it simultaneously encompasses characteristics of competitiveness and sustainability.

Eco-innovation develops within the boundaries of innovation systems according to institutional, cultural, economic, or historical characteristics, among others (Cooke et al., 1997). Given the diversity of contexts found in innovation systems, policymakers should have an in-depth knowledge of national innovation characteristics (Tödtling & Trippl, 2005). This knowledge is essential to implement policies and measures that stimulate innovation system agents to take actions based on sustainable development.

Governments do not always effectively drive eco-innovation because it is not only a phenomenon influenced by numerous factors (Díaz-García et al., 2015; del Río et al., 2010) but also incorporates the uncertainty and complexity of innovation and sustainability simultaneously. This paper recognizes the conditions that are sufficient or necessary to promote eco-innovation in European countries. For this purpose, a fuzzy-set qualitative comparative analysis (fsQCA) was performed. The conditions considered are (i) research institutions, (ii) human capital capacity, (iii) governance, (iv) private R&D investment, and (v) public R&D investment. The data for these conditions was obtained from different databases for 2021. These databases are Eco-Innovation Index, Governance Performance Index, European Innovation Scoreboard, and Scimago Institutions Rankings. The five conditions were selected due to their ability to stimulate sustainable action taking as agents of innovation systems (Horbach, 2016; Păcesilă & Ciocoiu, 2017; Rosca et al., 2018; Orlando et al., 2020).

2. Theoretical framework

The role of **research institutions** and universities is essential, especially in driving eco-innovation (Miozzo et al., 2016). Collaboration between research institutions, universities, and society facilitates the innovation agents' research, development, and innovation activities because research institutions offer a broad scope of business services and assistance (Lessard, 2014; Szutowski, 2021). In this sense, although authors defend the need for more research to confirm the relationship between eco-innovation and research institutions (e.g., Sáez-Martínez et al., 2016), most of the literature defends that this relationship is positive (e.g., del Río et al., 2017). Similarly, the existence of national **human capital** trained and aware of disruptive innovative techniques and sustainability is a key factor in increasing eco-innovation performance while facing economic, social, and environmental challenges (Zhen, 2011; Bossle et al., 2016).

Governments and policymakers can encourage the choices and actions of innovation system agents through several initiatives or measures. Therefore, their involvement in sustainable development based on eco-innovation is essential to achieving the effectiveness of such innovative and sustainable initiatives or measures (Chen et al., 2017; Smol et al., 2017). Some of the policy instruments implemented to develop eco-innovation are energy contracting, funds, or subsidies (Panapanaan et al., 2014). Moreover, governments can influence the collaboration between the innovation system agents, which favors the flow of experiences and knowledge on eco-innovation (del Rio et al., 2015; Pereira et al., 2020).

The literature shows no consensus on the influence of **R&D investment** on eco-innovation. While numerous studies argue that high levels of R&D investment guarantee the success of eco-innovations (Cheng and Shiu, 2012; Díaz-García et al., 2015; Mercado-Caruso et al., 2020), others advocate that the relationship between R&D investment and eco-innovation is neutral (O'Brien & Torugsa, 2011) or even negative (del Río et al., 2017; Horbach et al., 2013).

3. Methodology

Qualitative comparative analysis (QCA) is a methodology that allows the combination of qualitative and quantitative data, as well as their individual analysis (Ragin, 1987). This methodology is based on the principle of equifinality. Equifinality consists of the occurrence of an outcome that is explained by several mutually non-exclusive pathways (Wagemann & Schneider, 2010; Legewie, 2013). Thus, QCA holds the existence of different configurations of factors that involve the same outcome. The conditions or configurations may be present or absent in the explanation of the outcome (Schneider & Wagemann, 2012), as well as being sufficient or necessary to explain the outcome. Conditions are considered sufficient when they always trigger the outcome (Lucas & Szatrowski, 2014), even though the outcome may also occur when they are not present (Ragin, 2008; Roig-Tierno et al., 2017b). There may be other sufficient conditions that cause the outcome. In contrast, necessary conditions are present in all combinations that lead to the outcome (Lucas & Szatrowski, 2014). Particularly, this paper applies the fsQCA methodology due to the nature of the conditions and the outcome of the analysis (continuous variables).

4. Results of the necessity and sufficiency analyses

Considering both the absence and presence of the conditions, Table 1 shows the findings of **necessity analysis** for eco-innovation. Since the consistency threshold is not exceeded (0.9; Ragin, 2008; Schneider & Wagemann, 2012), the five conditions of the research model are not necessary. However, public R&D investment, human capital capacity, and research institutions are important conditions for triggering a country's eco-innovation because they present consistencies of 0.733, 0.762, and 0.802, respectively. Similarly, at least one type of investment in R&D (public or private) is relevant in explaining eco-innovation as it shows a consistency close to 0.8.

Table 1: Analysis of necessary conditions for eco-innovation

Conditions tested	Consistency	Coverage
Presence of		
Public R&D investment	0.733	0.774
Private R&D investment	0.653	0.807
Human capital capacity	0.762	0.779
Governance	0.559	0.6
Research institutions	0.802	0.788
Public or private R&D investment	0.786	0.726
Absence of		
Public R&D investment	0.312	0.295
Private R&D investment	0.366	0.307
Human capital capacity	0.299	0.291
Governance	0.56	0.522
Research institutions	0.262	0.266

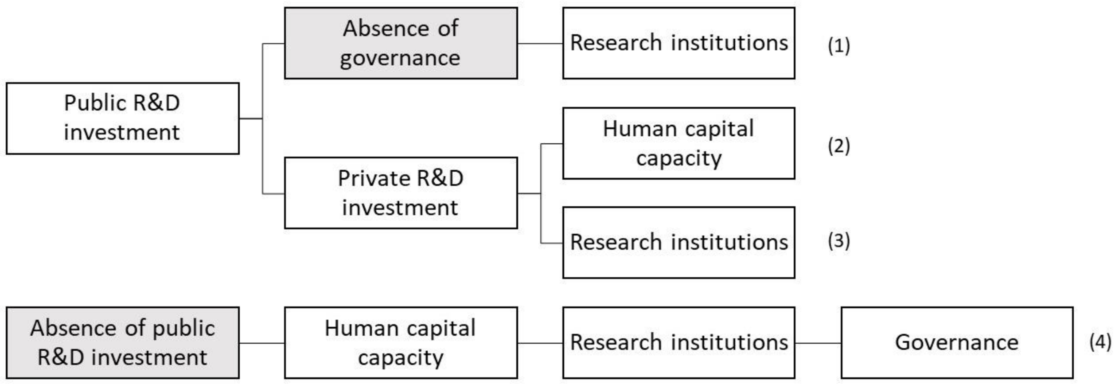
The findings of the **sufficiency analysis** are presented in Table 2. Model consistency must exceed the 0.75 threshold (Ragin, 2008) for the research model to be acceptable. In this case, the model presents a consistency of 0.9, being thus accepted. In addition, all configurations have a consistency higher than 0.85. The existence of four configurations or pathways that trigger eco-innovation corroborates the equifinality basis that characterizes QCA. Public investment in R&D and research institutions fit into three of the four configurations. This reflects that they are crucial in driving the eco-innovation phenomenon in a country. The different configurations of conditions are also illustrated in Figure 1.

Table 2: Recipes for eco-innovation

	MODELS			
Conditions	1	2	3	4
Public R&D investment	●	●	●	○
Private R&D investment		●	●	
Human capital capacity		●		●
Governance	○			●
Research institutions	●		●	●
Raw coverage	0.38	0.5	0.517	0.195
Unique coverage	0.044	0.072	0.087	0.133
Consistency	1	0.932	0.963	0.871
Solution coverage: **0.81**				
Solution consistency: **0.909**				

Note: Following the notation of Fiss (2011), "●" indicates the presence of a condition, whereas "○" indicates its absence. Large and small circles represent core and peripheral conditions, respectively. However, in this case, all conditions are core conditions represented by large circles.

Figure 1: Graphical representation of the pathways that lead to eco-innovation



The fsQCA allows to determine the conditions that trigger the absence of an outcome. In this paper, a necessity and sufficiency analysis were also conducted to identify the conditions and configurations that lead to the **non-occurrence of eco-innovation**. From the findings of the necessity analysis, the absence of private or public R&D investment is highlighted as a configuration that impedes the development of national eco-innovation. In contrast, the sufficiency analysis indicates that the role of human capital capacity is crucial because it appears in all the configurations of conditions of the research model. This last finding implies that the absence of human capital capacity hinders the eco-innovation development.

5. Discussion and conclusions

The uniqueness and originality of this studies lines in the analysis of necessary and sufficient variables instead of dependent or independent as in traditional regression methods. Eco-innovation is a phenomenon influenced by an immensity of factors because it incorporates the characteristics inherent to innovation and sustainability. This paper aimed to identify which conditions (research institutions, human capital capacity, governance, private R&D investment, and public R&D investment) and configurations of conditions are necessary and sufficient to trigger national eco-innovation.

The study emphasizes the importance of public investment in R&D, research institutions, and human capital capacity in stimulating eco-innovation in a country. Collaboration and cooperation between the agents of the innovation system can facilitate the flow of information, experience, know-how, and communication. In this way, some of the barriers countries face in promoting and encouraging eco-innovation could be removed. Innovation system agents participate actively in the eco-innovation process, having different effects on its implementation and progress. Therefore, awareness of sustainable development is the basis of current growth and competitiveness strategies. Eco-innovation is a crucial instrument that would foster the achievement of sustainable development.

The conclusions suggest several policy implications. Policymakers should design and implement policies that promote eco-innovation, considering both drivers and barriers. Countries should optimize and allocate limited resources since they cannot effectively address all the factors influencing eco-innovation. Moreover, the collaboration between countries and public and private organizations can provide new insights and perspectives to help in the allocation of resources, as well as compare eco-innovation performances and strategies applied to each national context. A reduction in inequalities in eco-innovation and sustainable development could be achieved through the active participation of all the agents of the innovation system. In this way, the gap between countries may be reduced, offering them similar future opportunities.

Keywords: eco-innovation, innovation systems, R&D investment, human capital, research institutions
JEL codes: I25, I28, O10, O30, O32, Q01

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