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# Ecological resource deficits as opportunities for environmental innovation across countries

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**Ecological resource deficits as opportunities for environmental innovation across countries**


## Abstract

**Purpose** - While previous research has identified that environmental innovation is shaped by a variety of drivers, researchers have devoted limited attention to the role of nature-based resources in the country. Building on environmental innovation theory and the natural resource-based view of the firm, this study introduces ecological resource deficits as a novel driver of environmental innovation. We explore how ecological resource deficits interacts with institutional and regulatory drivers as well as firm-level technology drivers to explain the extent of environmental innovation across different countries.

**Design/methodology/approach** - We apply fuzzy-set qualitative comparative analysis to a multi-source dataset to identify different pathways for environmental innovation across 28 countries.

**Findings** - Findings show that higher environmental innovation is a function of ecological resource deficits complemented by the presence of at least two other conditions. Moreover, the results show that environmental policy stringency and societal expectations are substitute conditions of environmental innovation.

**Originality/value** - This study reveals the interdependences between different conditions for environmental innovation across countries contributing to a more nuanced understanding of the geography of environmental innovation.



**Keywords** Ecological resource deficit, nature-based resources, environment, innovation, entrepreneurial opportunity, fsQCA

**Paper type** Research paper

**JEL Classification** - JEL O30, O13, P48, Q56

## 1. INTRODUCTION

The latest State of the Environment report by the European Environment Agency (2020) highlights that European countries are facing unprecedented environmental challenges. This concern is echoed at a global level, and a call for urgent action has been made (Ekins *et al*., 2019). While environmental degradation represents a problem, it also offers an opportunity for new value creation (York and Venkataraman, 2010). Indeed, entrepreneurship, through its potential for innovation, is a positive force to address environmental challenges (Shepherd and Patzelt, 2011) through environmental innovation defined as "*product, process, marketing, and organizational innovations, leading to a noticeable reduction in environmental burdens*" (Horbach *et al*., 2012, p.119).

Prior research has identified *institutional drivers* as well as *technology drivers* to be important for environmental innovation (Hojnik and Ruzzier, 2016). In this study, we introduce nature-based resources, and more specifically *ecological resource deficits*, as a novel driver of environmental innovation based on the following considerations. First, environmental innovation is distinctively different from other forms of innovation (Rennings, 2000) and drivers need to reflect on this better than is currently the case. The extent of ecological resources is relevant as deficits create unique pressure for environmental innovation, more so than for innovation generally. Second, environmental innovation reflects the geographical context in which it is embedded (Losacker *et al.,* 2021). The availability of ecological resources is location dependent, with some countries characterised by deficits and others by reserves (Collins and Flynn, 2015). This heterogeneity in nature-based resources is thus likely to explain differences in the extent of environmental innovation across geographies.

In their review of drivers of environmental innovation, Hojnik and Ruzzier (2016) criticise the almost exclusive use of variance theories in previous studies and the limitations associated with them. For example, variance research that relies on regression analysis cannot reveal the potential interdependence such as the complementarities and/or substitution between the different drives of environmental innovation. For example, previous studies have identified environmental policy stringency and government support (Hojnik and Ruzzier, 2016), environmental awareness (Horbach, 2016) or firms' technological capabilities (Valdez-Juárez and Castillo-Vergara, 2021) as drivers for environmental innovation, how the different drivers interact to lead to environmental innovation remains underexplored. Further, there is growing awareness that environmental innovation is a geographically specific phenomenon (Losacker *et al*., 2021), but research on environmental innovation across countries is still relatively rare (Frondel *et al*., 2007; Horbach *et al*., 2013; Horbach, 2016 providing exceptions), limiting our understanding of the geography of environmental innovation.

Building on environmental innovation theory (Horbach, 2008) and the natural resource-based view (Hart, 1995), this study explores *how ecological resource deficits interact with institutional as well as technology drivers to explain the extent of environmental innovation across different countries.*

To provide a more in-depth understanding of the complex interrelationships between these different drivers of environmental innovation, we apply fuzzy-set qualitative comparative analysis (fsQCA, Ragin, 2008) to a multi-source dataset to identify different pathways for environmental innovation across 28 countries. The causal conditions are based on single year data (i.e. 2009), whereas the outcome condition is based on a three-year average data covering 2009-2011 to account for potential time lags in developing environmental innovation. FsQCA, a set-theoretic approach, allows investigation of causal relationships depending on contextual conditions. In a recent systematic review, Kraus *et al.* (2018, p.33) conclude that fsQCA is becoming increasingly popular in entrepreneurship research (also see Muñoz and Dimov, 2015), because it can capture complexity "*through testing theory-based conditions and contextual influences rather than focusing on single effects of individual variables*". As fsQCA allows asymmetrical associations to emerge, it is a powerful approach to explain business outcomes in a highly complex and volatile environment (Kumar *et al*., 2022). Following the three-stage configurational theorising approach by Furnari *et al.* (2021) we first conduct a comprehensive literature review to *scope* relevant institutional as well as firm-level technology-side drivers that might in combination with nature-based resources explain environmental innovation. We then *link* the identified drivers in a configurational framework to illustrate the multiple different combinations that potentially explain environmental innovation. In the last step, we *name* each of the identified pathways and develop relevant propositions.

Findings from this study make several contributions: First, we extend environmental innovation theory by introducing ecological resource deficit as a novel driver of environmental innovation. This builds on a growing recognition of the opportunity for innovation inherent in nature-based resources (Davidsson, 2020; Wigger and Shepherd, 2020). Findings clearly show that the extent of environmental innovation across countries is dependent on their ecological resources – with ecological resource deficits leading to higher environmental innovation. Second, we advance understanding of the complex interaction effects between different drivers of environmental innovation. Findings suggest that innovative actor networks, form a necessary institutional driver of environmental innovation. This finding is novel as it highlights not only the relevance of external knowledge and R&D for environmental innovation, but the enabling role government plays in it. This points towards the importance of support that governments can provide compared to the regulatory pressures that it typically exercises through stringent environmental policies (Hojnik and Ruzzier, 2016). Findings also suggest that in the absence of formal institutional drivers i.e. stringent environmental policies, informal institutional drivers i.e. societal expectations become a substitute for environmental innovation in countries with high ecological resource deficits. However, societal expectations on their own are not a sufficient driver for environmental innovation in countries with low ecological resource deficits. This provides more nuance to the view that informal institutions might only be a second-best solution in the absence of reliable formal institutions (Durlauf and Fafchamps, 2004). Lastly, findings from this study explain why some countries have higher levels of environmental innovation than others addressing recent calls to advance understanding of the geography of environmental innovation (Losacker *et al.*, 2021). To the best of our knowledge, this study examines environmental innovation across the widest range of countries to date, including countries outside the EU and OECD and thus with different economic development profiles. This is relevant as it advances knowledge on the heterogeneity of environmental innovation across countries.

## 2. ENVIRONMENTAL INNOVATION THEORY: A GEOGRAPHICAL PERSPECTIVE

Environmental innovation theory suggests that aspects such as firms' technological capabilities, as well as environmental regulation and pressure groups, and environmental and social awareness are important drivers of environmental innovation (Horbach, 2008). Losacker *et al*. (2021, p. 3) have recently argued that there is a need for environmental innovation theory to also consider the spatial dimension as environmental innovation is an "inherently geographic phenomenon". This call follows a wider trend in innovation studies that highlight the relevance of geographic specificities for innovation and the need to provide a more nuanced analysis of the relationships between geography and innovation (Beynon *et al*., 2021; Hervás-Oliver *et al*., 2021; Parrilli *et al*., 2020).

Despite the growing awareness that innovation is often a geographically specific phenomenon (Losacker *et al*., 2021), the relevance of geographic specificities is still not yet well understood. Recent reviews show considerable inconsistencies concerning the role of different geographical drivers of environmental innovation, suggesting that prior studies have neglected consideration of the relevance of spatial dimensions (Díaz-García *et al*., 2015; Hojnik and Ruzzier, 2016). To the best of our knowledge, there are few prior studies (specifically Frondel *et al*., 2007; Horbach *et al*., 2013; Horbach 2016; Triguero *et al*., 2013) that explore the extent of environmental innovation across countries and the role country specific drivers play in explaining outcome heterogeneity.

These studies focus on European or OECD countries due to a lack of internationally comparative datasets. The most notable of these studies, is Horbach (2016), who explores the drivers of environmental innovation across 19 European countries. He highlights differences in the extent of environmental innovation between Western and Eastern European countries and the higher importance of regulatory drivers and lower importance of environmental awareness of the population in Eastern European compared to Western European countries. This both highlights the importance of geography in the discussion of environmental innovation but also indicates the way in which geography interacts with other factors to promote or impede environmental innovation. More attention therefore needs to be paid to drivers that reflect specific geographical features firms are embedded in. In the context of environmental innovation, we argue that it is particularly relevant to consider nature-based or ecological resources that might push firms to explore new opportunities.

### *2.1 The role of ecological resource deficits as a driver of environmental innovation*

Natural resource demands of countries increasingly exceed the Earth's capacity for biological regeneration. Ecological resource deficit thus happens when either biocapacity declines or resource use increases. It is a useful concept as it reframes policy debates away from considering ecological resources as an infinite, and thus key means of growth, to one that puts ecological deficits at the centre of consideration (Collins and Flynn, 2015). It also allows quantifying and standardising environmental degradation across countries, making the level of degradation facing the environment comparable between different geographies. Consequently, environmental degradation and its wider economic and societal effects are now the most pressing problems countries face (Alvarado *et al.,* 2021). An increasing body of literature suggests that innovation plays a vital role in mitigating environmental degradation (Sinha *et al.,* 2020).

The natural resource-based view (NRBV) of the firm (Hart, 1995) postulates that "the natural environment is a source of new and emerging business opportunities and firms that are able to adapt their activity to these constraints will drive the economy of the future" (Salvadó *et al*., 2012, p.10). The constraints imposed by the natural environment concerns the deficits of ecological or natural resources that are available to firms. As such, the NRBV emphasises the link between natural resources available to firms and their innovation. This is relevant, as prior research has primarily focused on the resources of firms and of the individuals behind the firms but has neglected to consider the importance of resources in the environment, and in particular the natural environment, as a source of innovation (Davidsson, 2020). Wigger and Shepherd (2020), for example, recently introduced the concept of nature-based opportunities arguing that both access to natural resources and preserving natural resources constitutes innovation opportunities. This extension of the entrepreneurial opportunity concept to include nature-based resources is highly relevant.

Implicit in the NRBV is the assumption that firms are increasingly constrained by the deterioration of the natural environment and the pressure that arises from increasingly scarce natural resources (Hart, 1995). Ecological resource deficits resulting, for example, from over-exploitation, create discontinuity or disruption that threatens firms' existing resources and capabilities (Hart and Dowell, 2011). As a result, *ecological resources deficits* create pressure that is not only a constraint, but arguably also has the potential to create innovation opportunities for firms. This is supported by Hörisch *et al.,* (2017) who found that higher ecological pressure results in stronger environmental orientations of entrepreneurs. The extent of environmental orientations of entrepreneurs can be shaped by ecological pressure in several ways. For example, ecological pressure presents new opportunities for entrepreneurs to address the market failure concerning environmental problems. As such, entrepreneurs might perceive environmentally oriented venture and innovation ideas more favourably. Ecological pressure can also indirectly influence entrepreneurs' willingness to pursue ideas that are environmentally oriented through the regulatory pull/push such as government support or environmental taxes enacted by government to tackle environmental problems (Horbach *et al*., 2012). However, the role of resource deficits as a driver of environmental innovation is not yet well understood (Vedula *et al.,* 2022).

*2.2 The role of institutional drivers of environmental innovation*

As natural resources are often seen as a common good, formal institutions govern their use through, for example, specific regulations and policies. In particular, environmental policy stringency and government support have been identified as two critically important institutional mechanisms driving environmental innovation (Hojnik and Ruzzier, 2016). Environmentally stringent policies put an explicit or implicit price on environmentally harmful behaviour. *Environmental policy stringency* is thus a valuable tool to regulate the environment while at the same time stimulate environmental innovation. Findings from previous research, however, are inconsistent regarding the relationship between a country's environmental policy stringency and its environmental innovation (Chu and Tran, 2022). One potential explanation is that highly stringent environmental regulation may result in undesirable results. As Chu and Tran (2022, p.2) pointed out, "highly stringent regulation can significantly increase the compliance cost", which in turn reduce the resources available for research and development of cleaner technologies. Prior research does show that differences in environmental policy stringency across countries are directly related to differences in levels of environmental innovation, suggesting that strict environmental regulations are an effective measure to stimulate environmental innovation (Cainelli *et al*., 2015; Hojnik and Ruzzier, 2016; Johnstone *et al*., 2012; Woerter *et al*., 2017). However, in their study of environmental innovation in the UK, Kesidou and

Demirel (2012) highlight that stringent environmental policies only encourage firms at the two extreme ends of the innovation spectrum. Specifically, it encourages the least innovative firms to invest in environmental innovation to increase efficacy, and the most innovative firms to increase their first-mover advantage. This suggests that other drivers are also needed to complement stringent environmental policies to mobilise a wider range of firms to develop environmental innovation.

Other than environmental policy stringency, environmental innovation theory also suggests that institutional structures in the form of innovation networks are another important driver of environmental innovation (Horbach, 2008). Governments can drive environmental innovation not only through creating regulatory pressure, but also through bringing relevant actors together and enabling interaction over specific environmental concerns (Meek *et al*., 2010; Wahga, Blundel and Schaefer, 2018). However, innovative actor networks as a type of *government support* have received comparably little attention in empirical studies (Hojnik and Ruzzier, 2016) and their effect on the development of environmental innovation is not yet well understood. Prior research has, however, argued that environmental innovation requires more external sources of information and knowledge and more R&D collaboration to solve technological problems (De Marchi, 2012; Triguero *et al*., 2013). It is important to solve the technological problems because the availability of technological resources and capabilities has been shown to drive environmental innovation (Horbach *et al.,* 2012). This would suggest that government support in the form of innovative actor networks might play a key role as a driver of environmental innovation.

*Societal expectations* concerning the environment are also an important informal institution that can drive environmental innovation. Levels of awareness for environmental concerns differ across geographies. In the European context, for example, environmental awareness being higher in Western European countries (Horbach, 2016). It has been argued that higher levels of environmental awareness results in higher levels of environmental innovation (Losacker *et al*., 2021), higher levels of awareness among the population translating into increased environmental innovation through increased pressure on businesses or governments. For example, Kesidou and Demirel (2012) show that consumer awareness of and pressure for increased corporate responsibility and environmentally friendly products and processes is increasingly becoming an important driver for environmental innovation.

### *2.3 The role of firms' technological capabilities*

Firms' technological capabilities form a corner stone not only in general innovation theory, but in environmental innovation theory as well (Horbach, 2008). Technological capabilities not only allow firms to introduce new environmental innovations, but also reduce risks created by imposition of new governmental environmental regulations (Horbach *et al.*, 2012). More recently, Valdez-Juárez and Castillo-Vergara (2021) also find that firms' technological capability both positively and significantly influences eco-innovation practices but also through such practices, financial performance. Skordoulis *et al.* (2020) found, however, that the effect of environmental innovation on firms' performance is linked to the national context within which they operate, which highlights the importance of including a geographical perspective in any framework examining this. While technologies create a push effect by creating new opportunities for innovation (Horbach, 2008), they are not specific to environmental innovation. Further, they do not reflect the spatial specificities firms are embedded in.

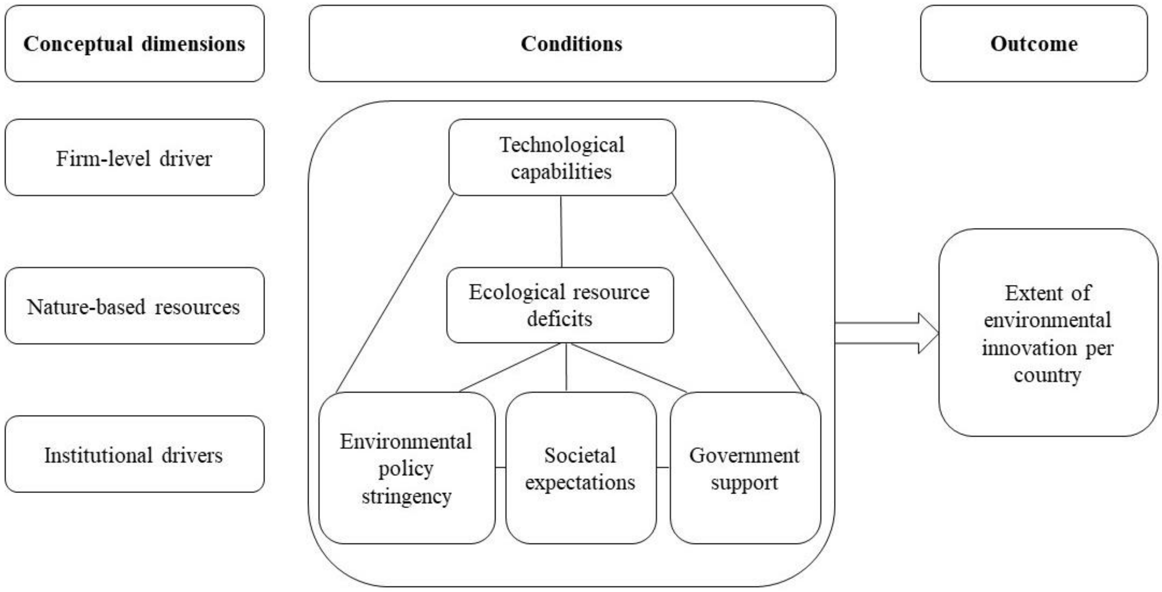
### *2.4 A configurational framework*

Building on environmental innovation theory, prior research suggests that there are different combinations of drivers of environmental innovation in different countries (Horbach, 2016), but an in-depth analysis considering complex interaction effects of different drivers, including ecological resource deficits, on the extent of environmental innovation across countries is still missing.

Figure 1 summarises our discussion thus far in a configurational framework, similar to what has been used in prior research (Beynon, Jones & Pickernell, 2021; Beynon *et al*., 2021). In line with Collins and Flynn (2015) ecological resource deficits are placed at the centre of consideration, given that they are a very important driver towards environmental innovation. However, it is unlikely that ecological resource deficit is a sufficient driver for environmental innovation. Instead, we argue that there is also a range of potential *complementary / substitutive* conditions, in the form of institutional as well as firms-level drivers. The complementarity exists when the occurrence of the outcome is accompanied by the presence of multiple conditions, whereas the substitution exists when the presence of one condition is accompanied by the absence of another condition. Having undertaken the *scoping* stage of the development of the configurational framework, reviewing the different categories of drivers of environmental innovation, it is also important, therefore, to look at potential interactions between the different drivers, explaining how they might complement or substitute for each other.

As firms' technological capabilities have been identified as a key driver of innovation in general (Horbach 2008), we expect it to complement other drivers as it might be difficult, for example, to exploit nature-based opportunities without them. However, compared to other types of innovation, environmental innovation suffers from the so-called double-externality problem (Losacker *et al*., 2021). This means environmental innovations not only generate knowledge externalities in the development phase, but also additional environmental externalities in the diffusion and adoption phases. Whilst these positive environmental spillovers benefit society as a whole, the costs are borne by the innovating firms alone. Because this results in significant underinvestment in environmental innovation (Rennings, 2000), environmental innovations often require additional institutional drivers (Porter and van der Linde, 1995) to stimulate firms' environmental innovations. This suggests that environmental policy stringency and/or government support might complement ecological resource deficits to explain environmental innovation. Further, Meek *et al*. (2010) argue, for example, that societal expectations regarding the natural environment either substitute or complement other regulatory drivers of environmental innovation. Horbach (2016) also argues that an environmentally aware population can put pressure on governments to require more stringent environmental regulations, through which environmental innovation is also influenced. Overall, societal expectations are increasing globally which might also increase their importance as driver of environmental innovation. If it is a sufficient driver on its own or how it interacts with other drivers, by either substituting or complementing them, is, based on previous evidence, difficult to tell. How the different drivers interact with each other, and which drivers complement or substitute each other is also likely to differ across countries. Consequently, we expect to find more than one pathway (sets of drivers), pathways representing different sets of countries, highlighting the spatial specificity of environmental innovation.

**Figure 1: Configurational framework**




## 3. METHODOLOGY

We applied fuzzy-set qualitative comparative analysis (fsQCA) to identify the pathways that can lead to environmental innovation. FsQCA is based on a configurational approach that allows us to examine causal conditions holistically (Ragin, 2008). It can help to uncover potential complexity concerning causal conjunction, equifinality, and asymmetry (Douglas *et al*., 2020; Schneider and Wagemann, 2012). More specifically, it can reveal how combinations of conditions work together to produce environmental innovation (causal conjunction); how the same outcome can be achieved through multiple ways (equifinality); and how the conditions leading to the presence of the outcome might not mirror those leading to the absence of the outcome (asymmetry). Therefore, we consider fsQCA an ideal approach to uncover the potential interdependences of different drivers leading to the presence or absence of environmental innovation.

### *3.1 Data*

This study integrates data from several sources. We collected data from the Organisation for Economic Co-operation and Development (OECD) for the number of patents on environment-related technologies in a country (OECD, 2019). We used data from the World Bank for the gross domestic product (GDP) per capita in a country (World Bank, 2019). The patent and GDP data were used to construct the outcome condition concerning environmental innovation as discussed below. Moreover, we used the

World Economic Forum (WEF) data for the extent of environmental policy stringency in a country (Blanke and Chiesa, 2009). We used Global Entrepreneurship Monitor (GEM) data for conditions concerning government support and societal expectations in a country (GEM, 2009). Data from the Global Footprint Network was used to capture the extent of ecological resource deficit in a country (Global Footprint Network, 2019). Finally, technological capabilities were captured using the World Economic Forum's Global Competitiveness Index dataset (World Economic Forum, 2017). Across these datasets, we were able to identify 28 countries as shown in Appendix A.

*3.2 Measures: Outcome of interest*

*Environmental innovation* was measured by using the average number of patents in environment-related technologies between 2009-2011 divided by the average of GDP per capita in the country. The technology domains concerning environment-related technologies are summarised in Appendix B. The number of patents includes the patent applications to the European Patent Office and the US Patent and Trademark Office. It is based on patent applications rather than patents granted because "it can take up to ten years in some cases" for a patent to be granted (OECD, 2009, p. 61). In contrast to all causal conditions that are measured based on single year values, we operationalised environmental innovation using the three-year average based on the following considerations. First, developing a patentable product or process tends to be costly and time consuming. This implies that there will be a time lag in the development of product or process that can be filed for patent protection. Second, due to the complex patent application process, there will be another time lag of 12 months between the domestic and foreign application dates (OECD, 2009). Using a three-year average can thus help to account for potential time lags in developing and applying for patents. Moreover, we divided the number of patents by the GDP per capita to account for differences in country size and income.

*3.3 Measures: Causal conditions*

*Ecological resource deficit* occurs when a country's ecological footprint exceeds its biocapacity. Specifically, it was measured using the ecological footprint of production (gha per person) divided by the biocapacity (gha per person) in the country. Global hectares (gha) are the accounting unit for the ecological footprint and biocapacity accounts (Global Footprint Network, 2019). The ecological footprint of production and biocapacity of a country are based on the 2009 data provided by the Global Footprint Network (2019). *Environmental policy stringency* was measured using data from the 2008 WEF Executive Opinion Survey (Blanke and Chiesa, 2009), which includes one question asking executives about the country's environmental regulation stringency, ranging from 1 (lax compared with most countries) to 7 (among the world's most stringent). *Government support* was measured using 2009 GEM National Expert Survey data, following Hörisch *et al.,* (2017). The survey covers one question asking the extent to which "the government is able to bring potential entrepreneurs, businesses and CSOs together around specific social/environmental or community projects", with a response ranging from 1 (completely false) to 5 (completely true). *Societal expectations* were also measured using data from 2009 GEM National Expert Survey that asked, "In my country, society expects companies to give some of their profits back to the community through contributing to important social or environmental projects", with a response ranging from 1 (completely false) to 5 (completely true).

Finally, *technological capabilities* were measured using the 2009 data from the World Economic Forum's Global Competitiveness Index dataset (World Economic Forum, 2017). Specifically, this condition is measured based on two questions. The first question is about the availability of latest technologies: "In your country, to what extent are the latest technologies available? [1 = not at all; 7 = to a great extent]". The second question is about firm-level technology absorption: "In your country, to what extent do businesses adopt the latest technologies? [1 = not at all; 7 = to a great extent]". We used the average of the two items to represent technological capabilities.

### *3.4 Data calibration*

Data calibration is the process of transforming the data into fuzzy membership scores. This process requires setting three anchoring points to represent full non-membership (0), cross-over point (0.5), and full membership (1) based on substantive, theoretical knowledge (Ragin, 2008). The calibration of the outcome condition environmental innovation was informed by previous theoretical and substantive knowledge. Specifically, according to European Commission's (2014) Regional Innovation Scoreboard, regions with innovation output 20% or more above the EU average is considered as innovation leader and those with outputs below 50% of the EU average is consider as modest innovators. Building on this knowledge and also following previous fsQCA study that examines the innovation output of different regions (e.g., Domenech *et al.*, 2016), we used adjusted mean x 0.50, adjusted mean, and adjusted mean x 1.20 to represent the three anchoring points, respectively, for environmental innovation. The adjusted mean (i.e., 1.32) was calculated based on the full sample, excluding four extreme cases (i.e., China, United Kingdom, Republic of Korea, and United States). We excluded the extreme cases, following Hudson and Kühner (2013), because they can distort the sample mean especially when the sample size is small. Extreme cases were identified based on a standard score of 2.5 or greater following the suggestion by Hair *et al.*, (2014). It is worth noting that the extreme cases were excluded only in the process of computing the adjusted mean to establish the three calibration thresholds. They were included in the formal analysis to identify the pathways that can lead to environmental innovation.

For causal conditions, including environmental policy stringency, government support, societal expectations, and technological capabilities, we used mean - one standard deviation, mean, and mean + one standard deviation, respectively, to represent the three anchoring points. This is in line with the best practices suggested by Douglas *et al.*, (2020) to use consistent calibration cut-offs across the conditions when there are no strong theoretical reasons to modify this calibration rule. Finally, for ecological resource deficit, we used 1, 1.46, 1.92, to represent the three anchoring points, respectively. The value of 1.46 is derived based on the median of the 28 countries included in the present study. A value of 1 implies the biocapacity and footprint in the country is balanced. The value of 1.92 is derived to ensure that distance between fully in and cross over point (e.g., 1.92 – 1.46 = 0.46) is equal to the distance between cross over point and fully out (e.g., 1.46 – 1= 0.46). Table 1 shows the sample characteristics and calibration thresholds.

Table 1: Sample characteristics and calibration thresholds

| Conditions | Min | Max | Mean | Std. | Fully out | Cross over | Fully in |
|---|---|---|---|---|---|---|---|
| Environmental innovation | 0.00 | 213.43 | 16.47 | 47.14 | 0.66 | 1.32 | 1.58 |
| Ecological resource deficit | 0.41 | 12.00 | 2.17 | 2.26 | 1.00 | 1.46 | 1.92 |
| Environmental policy stringency | 2.50 | 6.20 | 4.44 | 1.02 | 3.42 | 4.44 | 5.46 |
| Government support | 1.63 | 3.88 | 2.68 | 0.50 | 2.18 | 2.68 | 3.17 |
| Societal expectations | 2.94 | 4.44 | 3.62 | 0.36 | 3.25 | 3.62 | 3.98 |
| Technological capabilities | 3.29 | 6.38 | 5.06 | 0.88 | 4.17 | 5.06 | 5.94 |

## 4. DATA ANALYSIS AND RESULTS

### *4.1 Necessity analysis*

We first conducted necessity analysis to assess whether any of the causal conditions examined in our study were necessary for the presence or absence of environmental innovation. We applied a consistency threshold of 0.90 (Schneider and Wagemann, 2012) and a coverage threshold of 0.65 (Muñoz *et al.*, 2022). As shown in Table 2, the consistency and coverage scores for all causal conditions are below the recommended threshold. This indicates that none of the causal conditions is a necessary condition for the outcome.

Table 2: Analysis of necessary conditions for the presence and absence of environmental innovation

| | Presence | | Absence | |
|---|---|---|---|---|
| Causal conditions* | Consistency | Coverage | Consistency | Coverage |
| Ecological resource deficit | 0.80 | 0.66 | 0.35 | 0.38 |
| ~Ecological resource deficit | 0.25 | 0.23 | 0.69 | 0.82 |
| Environmental policy stringency | 0.73 | 0.65 | 0.36 | 0.41 |
| ~Environmental policy stringency | 0.34 | 0.29 | 0.69 | 0.77 |
| Government support | 0.75 | 0.63 | 0.39 | 0.42 |
| ~Government support | 0.31 | 0.28 | 0.66 | 0.77 |
| Societal expectations | 0.52 | 0.43 | 0.56 | 0.59 |
| ~Societal expectations | 0.50 | 0.46 | 0.46 | 0.56 |
| Technological capabilities | 0.81 | 0.70 | 0.31 | 0.35 |
| ~Technological capabilities | 0.24 | 0.21 | 0.73 | 0.83 |

* ~ sign refers to absence of the causal condition

### *4.2 Sufficiency analysis*

We then conducted sufficiency analysis to identify the configuration of conditions that are sufficient to produce environmental innovation with the help of a truth table (Ragin, 2008). The truth table (shown in Appendix C) contains 32 logically possible configurations based on the five conditions ($2^5$) examined in the present study. Each row of the truth table represents one potential configuration that might (or might not) contain empirical case(s) leading to the outcome. Given that the sample size is small, we applied a frequency threshold of 1 and removed rows or configurations that contain no empirical cases (Douglas *et al*., 2020). Based on a consistency threshold of 0.75 (Ragin, 2008) and a proportional reduction in inconsistency (PRI) threshold of 0.65 (Douglas *et al*., 2020), configurations above the threshold were coded as 1 or 0 otherwise.

Table 3: Pathways for the presence or absence of environmental innovation

| | Presence of outcome | | Absence of outcome | | |
|---|---|---|---|---|---|
| Causal Conditions | P1 | P2 | A1 | A2 | A3 |
| Nature-based resources | | | | | |
| Ecological resource deficit | ● | ● | | ○ | ○ |
| Institutional drivers | | | | | |
| Environmental policy stringency | ○ | ● | ○ | ○ | ● |
| Government support | ● | ● | ○ | | ○ |
| Societal expectations | ● | ○ | ○ | ● | ● |
| Firm-level driver | | | | | |
| Technological capabilities | | ● | ○ | ○ | |
| Consistency | 0.78 | 0.78 | 0.87 | 0.98 | 0.86 |
| Raw coverage | 0.22 | 0.29 | 0.30 | 0.35 | 0.11 |
| Unique coverage | 0.17 | 0.24 | 0.19 | 0.23 | 0.04 |
| Overall solution consistency | 0.83 | | | | |
| Overall solution coverage | 0.46 | | | | |

Note: ● (○) represents the presence (absence) of the condition

We then performed two separate analyses with the presence and absence (~) of environmental innovation as the outcome condition. Table 3 shows the results from sufficiency analysis. It is worth noting three solutions were generated from the analysis: complex, parsimonious, and intermediate. The complex solution avoids using logical remainders, which refer to configurations that entail no empirical cases, whereas the parsimonious entails all logical remainders; the intermediate solution includes only the logical remainders that are consistent with prior theoretical and substantive knowledge (Ragin, 2008). We report the results based on the complex solution due to lack of strong theoretical basis to make assumptions about the logical remainders.

The overall solution consistency for the presence or absence of environmental innovation are both above the recommended value of 0.80 (Ragin, 2008). The overall solution coverage of 0.46 (0.58) for the presence (absence) indicates that a substantial proportion of the cases are explained by the identified pathways. The existence of two presence of two presence of environmental innovation pathways and three absence of environmental innovation pathways confirm the existence of equifinality, that they all involve combinations of presence and / or absence of multiple conditions confirms causal conjunction, and that none of the presence pathways are mirror images of an absence pathway shows the existence of asymmetry. Overall this indicates the relevance of the use of fsQCA.

Pathway P1 shows that presence of societal expectations in combination with the presence of governmental support and ecological resource deficit can result in environmental innovation, even when environmental policy stringency is absent, and technological capabilities non relevant. P1 is thus labelled “dual nature/market-based opportunity”. In contrast, pathway P2 shows that the presence of environmental policy stringency in combination with government support, ecological resource deficit, and technological capabilities, can lead to environmental innovation even when societal expectations are absent. This pathway thus represents “nature-based opportunities supported by policy”.

Pathway A1, where there is an absence of all institutional drivers and technological capabilities, and non-relevance of ecological resource deficit, can be labelled “lack of urgency”. Pathway A2 labelled “insufficient market opportunity” shows that the presence of societal expectations when combined with the absence of environmental policy stringency, technological capability and ecological resource deficit can result in the absence of environmental innovation, where government support is irrelevant. Finally, pathway A3 represents what we label “lack of opportunity” indicating that the joint absence of government support and ecological resource deficit can lead to absence of environmental innovation, even where environmental policy stringency and societal expectations are present. Table 4 then provides a summary of pathways and their respective labels, representing the third stage of the configurational theorising approach advocated by Furnari *et al.* (2021).

To scrutinise the results, we also performed another test by adjusting the PRI threshold as recent research suggests a higher threshold of > 0.70 is preferable (Greckhamer *et al.*, 2018). The pathways identified from the robustness test are identical to those identified from our main analysis, providing further support to our results.

Table 4: Naming of pathways

| Pathway | Description | Name |
|---|---|---|
| P2 | Presence of ecological resource deficit in combination with environmental policy stringency and government support | Nature-based opportunity supported by policy |
| P1 | Presence of ecological resource deficit in combination with government support and societal expectations | Dual nature/market-based opportunity |
| A1 | Absence of all institutional drivers and technological capabilities, and non-relevance of ecological resource deficit | Lack of urgency |
| A3 | Absence of ecological resource deficit and government support, where all other environmental innovation conditions are present or irrelevant | Lack of opportunity |
| A2 | Presence of societal expectation in combination with absence or irrelevance of all other drivers | Insufficient market opportunity |

## 5. DISCUSSION AND IMPLICATIONS

Previous research has already highlighted the positive relationship between a country's level of economic development and its ecological deficit. With increasing levels of industrialisation, demands for infrastructure and consumption are also rising, leading to environmental degradation and consequently higher ecological pressure (Alvarado *et al*., 2021). In terms of the presence of environmental innovation, the findings (see pathways P1 and P2) show that ecological pressure in the form of resource deficits is a necessary, but not sufficient driver of environmental innovation. However, whilst in countries where ecological resource deficits are present environmental innovation is also present, where ecological resource deficits are absent, environmental innovation may be absent (see pathways A2 and A3), or not relevant (A1). This points towards the growing importance of nature-based or ecological opportunities vis-à-vis market-based opportunities as a driver of environmental innovation (Wigger and Shepherd, 2020; York and Venkataraman, 2010).

> *Proposition 1: The presence of ecological resource deficit is a necessary, but not sufficient driver for the presence of environmental innovation.*

However, the results also show that the presence of ecological resource deficit also needs to be complemented by other drivers, most obviously government support. Which other complementary drivers are relevant, however, depends on the country context. Looking at the countries that are associated with pathways P1 and P2, we find interesting nuances that suggest important theoretical and practical implications, particularly given the more all-encompassing nature of the analysis, across a range of geographical contexts that is undertaken in this study compared to others discussed in the literature (most notably, De Marchi, 2012; Frondel *et al.*, 2007; Horbach, 2008; Horbach *et al.*, 2013; Johnstone *et al*, 2012; Kesidou and Demirel, 2012; Sinha *et al*, 2020; Triguero *et al.*, 2013; Woerter *et al.*, 2017).

Countries associated with P2 include Belgium, Spain, and the United Kingdom, whilst countries associated with P1, include China and Saudi Arabia. In both pathways ecological resource deficits and government support are necessary conditions, extending De Marchi's (2012) research to include different country contexts. In P2, however, these conditions are complemented by stringent environmental policies, whereas in P1, they are complemented by societal expectations. This provides more nuance to Kesidou and Demirel's (2012) findings suggesting that this difference is likely grounded in the specific country context. This may be because in P2 countries the externalities generated by innovations, the pathway also showing presence of firm technological capabilities, are higher, therefore requiring higher environmental policy stringency, especially given that in these P2 countries societal pressure is absent. In P1 countries, however, where environmental policy stringency from government is absent, societal expectations play this driving role. Taken together, a comparison between pathways P1 and P2 indicates that for environmental innovation to be present, environmental policy stringency and societal expectations are *substitute* conditions such that the presence of one condition is accompanied by the absence of another condition.

This is interesting, given that institutional theory has explained that formal institutions are often themselves the result of informal institutions of a country, for example, where certain beliefs in society (e.g. environment must be protected from human behaviour) are translated into formal rules and laws that articulate this belief legally (e.g. stringency of environmental policy), through democratic political processes. Whilst it may therefore seem strange that presence of environmental innovation may be explained by a pathway (P2) including the presence of environmental policy stringency and absence of societal expectations, the presence of firm technological capabilities may suggest that firms may be driving as well as reacting to environmental policy stringency. This would be consistent with Valdez-Juárez and Castillo-Vergara (2021), where a government and its firms recognise that technological capability positively and significantly influences eco-innovation practice.

*Proposition 2a: For environmental innovation to be present, ecological resource deficit needs to be complemented by government support as a formal institutional driver.*

*Proposition 2b: Where firms' technological capabilities are also present, environmental policy stringency as a formal institutional driver substitutes societal expectations as an informal institutional driver.*

Countries associated with the absence of environmental innovation are Argentina, Chile, Latvia, Peru, Slovenia and Hungary for A3 and Panama, Colombia and Croatia for A2. Venezuela, Guatemala and Ecuador are associated with both pathways. For pathways A3 and A2, the absence of ecological resource deficit is a key condition, but insufficient to explain the outcome. For A3 countries, combination with a lack of government support suggests a lack of policy focus in bringing innovation actors together, or because such actors do not exist in sufficient numbers, perhaps because their reliance on primary production in their economy and/or focus on industrialisation has not yet put sufficient ecological pressure on their government to actively support such measures, even though societal expectations and environmental stringency are present. For A2, the presence of societal expectations combined with the absence of firm level technological capabilities, environmental policy stringency and ecological resource deficit may suggest that whilst there is societal awareness of environmental concerns, these societal expectations do not exercise sufficient pressure on their own to result in environmental innovation. This finding is in line with previous research that also suggested that firms' organisational capability and stringent regulation is more important to stimulate environmental innovation compared to societal expectations (Kesidou and Demirel, 2012). Consequently, we argue that in the absence of ecological pressure, firms' lack of technological capabilities to take advantage of any opportunities that may accrue and governments' lack of stringent environmental policy to drive serious innovative change, societal expectations, even if high, might have no effect. Venezuela, Guatemala, and Ecuador being associated with both pathways highlights that in these countries both mechanisms apply, perhaps unsurprising given their economic reliance on oil and agricultural products.

> *Proposition 3: The absence of environmental innovation is explained by a combination of absence of ecological resource deficits, absence of institutional drivers, and absence of technological capabilities.*

*5.1 Implications*

The results indicate the complexity of the topic and the key role geography plays, in the form of ecological resource deficits. As more countries are likely to face these ecological pressures in the future, however, there are important policy implications for government and society, as well as for entrepreneurs. This is important because environmental innovation is still a novel field and thus more dependent on external sources of information (Horbach, 2016).

Innovative actor networks play a significant role in the exchange of information and knowledge amongst a diverse group of actors including for example higher-education institutions, NGOs, and businesses. Governments can facilitate this exchange by actively supporting the development and implementation of such innovative actor networks. This points towards the important role of governments as enablers of environmental innovation and not just as regulators through for example implementing stringent environmental policies.

From an institutional perspective, innovative actor networks create normative pressures rather than coercive pressure resulting from stringent environmental regulations. Thus, the two drivers represent different mechanisms. For example, in some cases policy stringency complements government support, in other cases government support does not require the more coercive mechanism of stringency. This finding concerning the role of innovative actor networks facilitated by governments seems novel, having not previously been explored in combination with other drivers. Most previous studies have explored policy stringency i.e. coercive pressure, but the role of government in exercising normative pressure remains underexplored and is not yet well understood.

Further, findings show that societal expectations are not a sufficient driver of environmental innovation across all country contexts. This confirms research conducted a decade ago (Kesidou and Demirel, 2012) and implies that little has changed since. The social and environmental expectations of a country's populations, while seemingly increasing, are still less relevant compared to other drivers of environmental innovation. Nonetheless, the role of societal expectations as a substituting force in the absence of stringent environmental regulations should not be overlooked. Particularly, countries with high ecological resource deficits but weak formal institutions might benefit from the normative pressure exercised by a socially and environmentally aware population. In contrast, in countries that lack ecological resource deficits, normative pressure on its own is not a sufficient condition for environmental innovation.

This finding thus provides more nuance to the long held view that, in the absence of strong formal institutions, informal institutions are less efficient (Durlauf and Fafchamps, 2004). We argue that in the absence of strong formal institutions, it depends on other exogenous conditions whether informal institutions are efficient or not. What that means for environmental innovation is that informal institutions can be efficient, even in the absence of strong formal institutions, but only in countries with high ecological resource deficit. The importance of better understanding the interactions between such formal and informal institutions across different geographical contexts has long been pointed out (Rodriquez-Pose and Storper, 2006), and future studies using longitudinal data would also help to identify how the two evolve through time and in relation to each other.

Finally, for entrepreneurs, the results indicate that ecological resource deficits can constitute an important source of environmental innovation. As ecological degradation is increasing globally, the concept of regenerative businesses i.e. businesses that not only sustain but restore and enhance nature-based resources, is starting to attract attention (Hahn and Tampe, 2020). Depending on the institutional environment, firms' technological capabilities can be of key relevance in transforming opportunities arising from ecological resource deficits into environmental innovation. Further, entrepreneurs are also cautioned to not disregard government support in the form of innovative actor networks, but to support such networks through active engagement as they are important drivers of environmental innovation in in ecological resource-constrained environments.

## 6. CONCLUSIONS

In their recent review Vedula *et al.* (2022) urge researchers to explore the role of resource-scarcity as a driver of environmental innovation, a discussion that has been mostly absent from the literature. We offer new insights into the type of opportunities – opportunities created by natural resource deficits – that drive environmental innovation. Our findings suggest that economically advanced countries suffer from ecological resource deficits which in turn create pressure that drives environmental innovation.

An important limitation of this study is the relative age of the data used. We are unable to identify and use more recent data due to the lack of data that covers sufficient countries for the same time frame from multiple data sources. Despite this limitation, our findings are still relevant as recent data from the Global Footprint Network (2019) has shown an increasing trend in ecological resource deficit globally. This implies that countries are likely to face increasing pressure to mitigate the ecological deficit through environmental innovation.

Further, to what extent environmental innovation has already resulted in a decrease of the countries' natural resource usage or an increase of their biocapacity is not evident, though ideally, one would expect that countries with high environmental innovation will over time improve their ecological footprint. This dynamic was not possible to capture with the available data. Building a dataset that allows to track the identified pathways over time, would improve our understanding of the stability of these pathways. However, lack of longitudinal data and inconsistent measures has long been acknowledged (Horbach, 2008; Hussain *et al*., 2022). This problem is exacerbated when studying environmental innovation across countries, as measures are often unavailable across countries, inconsistent or cover incompatible timeframes. Data that is available across countries, such as GEM data used in this study, is often based on perceptions which might not necessarily accurately reflect actual behaviour.

Despite this limitation, we believe that we have managed to develop a robust set of conditions across many countries, making this study an important attempt to explore the geography of environmental innovation. We have used broad measures of environmental innovation as well as ecological deficit. Future research could use more specific measures to provide a more finely grained picture of the nature of ecological pressures and the nature of environmental innovation. For example, Hussain *et al.* (2022) found a negative effect of energy costs on firm innovation in Sub-Saharan Africa which could be an important boundary condition for the relationship between nature-based resources and environmental innovation in specific geographical context. Given the urgency related to renewable energy transition, this line of research has the potential to contribute to a more in-depth understanding of the mechanisms that drive distinct types of environmental innovation across different country contexts.

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**Appendix A. List of Countries**

| Country Name | Income group* |
|---|---|
| Ecuador | Lower-middle income |
| Guatemala | Lower-middle income |
| Tunisia | Lower-middle income |
| China | Lower-middle income |
| Bosnia and Herzegovina | Upper-middle income |
| Panama | Upper-middle income |
| Peru | Upper-middle income |
| Venezuela | Upper-middle income |
| Argentina | Upper-middle income |
| Colombia | Upper-middle income |
| Chile | Upper-middle income |
| South Africa | Upper-middle income |
| Latvia | High income |
| Slovenia | High income |
| United Arab Emirates | High income |
| Croatia | High income |
| Greece | High income |
| Norway | High income |
| Hungary | High income |
| Saudi Arabia | High income |
| Finland | High income |
| Belgium | High income |
| Spain | High income |
| Netherlands | High income |
| Denmark | High income |
| United Kingdom | High income |
| Republic of Korea | High income |
| United States | High income |

* The income groupings: low (<= 995), lower-middle (996-3,945), upper-middle (3,946-12,195), and high income (> 12,195) are adopted based on the World Bank's classification. Income is measured using gross national income (GNI) per capita, in U.S. dollars. The data is for calendar year 2009.

**Appendix B. Environment-related technologies**

| General environmental management | |
|---|---|
| Climate change mitigation | Climate change mitigation technologies related to energy generation, transmission, or distribution |
| | Climate change mitigation technologies in the production or processing of goods |
| | Climate change mitigation in information and communication technologies (ICT) |
| | Capture, storage, sequestration, or disposal of greenhouse gases |
| | Climate change mitigation technologies related to transportation |
| | Climate change mitigation technologies related to buildings |
| | Climate change mitigation technologies related to wastewater treatment or waste management |

Source: OECD (2019)

## Appendix C. Truth Tables

Table A.1 Truth table for the presence of environmental innovation

| Environmental policy stringency | Government support | Societal expectations | Ecological resource deficit | Technological capabilities | Number of cases | Environmental innovation | Raw consist. | PRI consist. |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 1 | 3 | 1 | 0.78 | 0.77 |
| 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0.77 | 0.75 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0.75 | 0.73 |
| 1 | 1 | 1 | 1 | 1 | 4 | 0 | 0.72 | 0.70 |
| 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0.68 | 0.66 |
| 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0.64 | 0.52 |
| 1 | 1 | 0 | 0 | 1 | 3 | 0 | 0.64 | 0.60 |
| 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0.54 | 0.50 |
| 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0.50 | 0.24 |
| 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0.40 | 0.28 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0.39 | 0.34 |
| 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0.30 | 0.07 |
| 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0.16 | 0.02 |
| 0 | 1 | 1 | 0 | 0 | 3 | 0 | 0.15 | 0.03 |
| 0 | 0 | 1 | 0 | 0 | 4 | 0 | 0.12 | 0.02 |

Note: 0 represents non-membership in the set; 1 represents full membership in the set

Table A.2 Truth table for the absence of environmental innovation

| Environmental policy stringency | Government support | Societal expectations | Ecological resource deficit | Technological capabilities | Number of cases | Environmental innovation | Raw consist. | PRI consist. |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 0 | 0 | 4 | 1 | 0.98 | 0.98 |
| 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0.98 | 0.98 |
| 0 | 1 | 1 | 0 | 0 | 3 | 1 | 0.97 | 0.97 |
| 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0.95 | 0.93 |
| 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0.84 | 0.76 |
| 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0.76 | 0.72 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0.69 | 0.66 |
| 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0.61 | 0.48 |
| 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0.54 | 0.50 |
| 1 | 1 | 0 | 0 | 1 | 3 | 0 | 0.46 | 0.40 |
| 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0.39 | 0.34 |
| 1 | 1 | 1 | 1 | 1 | 4 | 0 | 0.33 | 0.30 |
| 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0.32 | 0.27 |
| 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0.29 | 0.25 |
| 1 | 1 | 0 | 1 | 1 | 3 | 0 | 0.28 | 0.23 |

Note: 0 represents non-membership in the set; 1 represents full membership in the set