What leads to investment in sustainable building?
An MCA-PCA approach

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We use the PITEC database on innovation activities by Spanish SMEs to perform a multivariate statistical analysis to identify the most relevant factors for firms to invest in new products and production processes in the sectors of construction, engineering and elaboration of different building materials. We explore 41 indicators from four domains (innovation decisions, organisational, technological and environmental characteristics), with a special focus on financial constraints. The exploratory results obtained suggest product and process innovation tend to come together, while two are the key factors that determine whether firms invest in sustainable building or not. First, smaller and younger companies invest more frequently in new products and production processes; second, firms that have restricted access to financial sources – either internal or external – do not innovate.
KEYWORDS: investment decisions, sustainable building, innovation, MCA-PCA

1. INTRODUCTION

Innovation is a key driver of corporate value for firms in any sector. There is evidence of a positive relationship between innovation and superior performance (eg, [1]), such that firms that do not invest in innovative activities, processes or strategies, take the risk of becoming uncompetitive [2]. These lessons apply to investment in sustainable building, as well as to related sectors – furniture, manufacture of non-metallic mineral products, construction of buildings, civil engineering, etc. Environmentally sustainable building construction has experienced significant growth, particularly as society has become more aware of the impact of greenhouse gas emissions and natural resource consumption [3]. Researchers have recognized the need to implement innovative technologies for sustainable building as early as [4] and [5]. Here, the literature has focused on organisational difficulties entailed by the adoption of the new technologies [6], particularly the importance of financial constraints as a key barrier to innovation [7, 8], and the potential for fiscal measures to incentivize innovation [9]. Indeed, any new investments must be conceived in a way that they reduce the risks associated: nearly 50% of new products fail in the market [10].

Understanding the drivers of investment decisions by small firms in Spain to develop new, sustainable building materials and techniques, is the main target of our analysis here. We use the Spanish Technological Innovation Panel (PITEC) database, which provides annual survey information on the characteristics and innovative activities of a large set of firms. In our analysis, we consider all small and medium enterprises (SMEs) that are identified in the PITEC database as with "no incidents" and with activity (positive revenues) in years 2010 to 2014. We filter the following sectors of interest: manufacture of wood and of products of wood and cork, manufacture of other non-metallic mineral products, manufacture of furniture, construction of buildings, civil engineering, and specialised construction activities. We did not include some sectors that would be of interest for this research, because they are mixed with other sectors in the PITEC database, such as chemicals, energy and water, and architectural and engineering activities.

We use the technology-organisation-environment (TOE) approach as a conceptual framework, in order to identify some recurrent domains in the literature of determinants of innovation. We analyse internal variables to the firm as well as external and environmental variables. Moreover, following the importance of financial constraints, we put special focus on financial resources available to the firms, the relative advantage of the innovation and the costs required to develop it, and the influence of institutional partners. We conduct an exploratory study to identify the most relevant factors among a large list of indicators retrieved from the literature. For an exploratory analysis performed to investigate several interconnected causes without hierarchical causality, linear and hierarchical approaches should be avoided. Therefore, we perform a multivariate statistical analysis based on multiple correspondence analysis (MCA) and principal component analysis (PCA) combined, to explore the main drivers of innovation among 41 indicators from four domains, including innovation decisions, organisational, technological and environmental characteristics.

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The rest of the article is structured as follows. First, we briefly develop the conceptual framework, and describe the sample and data of analysis. In the core of our research, Section 3 deals with the multivariate analysis of our data, and the discussion of the main results obtained. Section 4 offers a set of conclusions.

2. CONCEPTUAL FRAMEWORK, SAMPLE AND DATA

The EU Community Innovation Survey (CIS) defines innovation as the introduction of a new or significantly improved product, process, organisational method or marketing method by a firm, implying newness in relation to products, processes, or business practices. More than invention alone, innovation can be regarded as an investment appraisal that involves the spotting of opportunities by the firm, considering the risks involved, and taking actions trying to profit out of them [11].

2.1 Determinants of investment decisions to innovate

Under a resource-based view of the firm, for which firm value stems from the combination of resources that are difficult to imitate or imperfectly mobile across firms, a frequent conceptual framework for innovation decisions is TOE. According to it, the factors that determine innovation are both internal (the managers and the firm), and external, that is, the characteristics of the innovation itself and the environment [12]. The list of factors to be included depend on the sector of analysis, but some recurrent domains are identifiable. We group them as internal factors and external factors.

In terms of internal factors, authors often test the sociodemographic profiles of entrepreneurs (age, education, income) and their attitudes (perceived benefits, performance expectations, support and readiness, management strategy and creativity), firm characteristics (size (employees and capital base), products, IT usage habit) and business orientation (source of management information, social influence and facilitating conditions). Recent examples are [13] and [14]. Regarding external factors, authors focus on the technological characteristics of the innovation (expected increase in productivity, relative advantage, cost, security, compatibility and complexity), and on environmental factors (degree of competition, value chain partners (customers and suppliers) and institutional partners). Recent examples are [12], [15] and [16].

Identifying the determinants of investment in innovative products and processes for sustainable building and architecture is a growing field of research in the last decade. Here, [6] highlight the main tools (CEO leadership, workers' competence, cooperation and networking) and barriers (financial constraints, timing, and lack of client understanding) for innovation by Finnish firms. [17] argues that inter-organizational relationships such as professional commitment to sustainability are key determinants. [18] also highlight the importance of CEO commitment to position the firm as an environmental leader, while institutional factors are less relevant. Financial constraints are major barriers that lead to the slow development of a more sustainable building sector [7]. In order to become mainstream, the sector must not only preserve the environment but also yield financial benefits to users and investors [8]. However, the ability to deliver a green project within acceptable cost constraints is often a key barrier [3]. In the same line, [9] suggest that fiscal measures might incentivize investors attitudes towards a sustainable behaviour. Finally, [19] find that cost-effectiveness is determinant for project success.

The statistical approach we use is similar to that applied in a series of articles. [20] explore the factors that affect information adoption by farmers with PCA. [21] use exploratory factor analysis and multivariate regression to identify IT adoption factors in the auto ancillary industry. [22] relate innovation investment decisions by firms in rural areas to organizational, technological, and environmental factors, with a two-step statistical approach that combines MCA and PCA.

2.2 Sample and variables

We use data from PITEC database, which provides information on innovation activities by a sample of Spanish firms. We retrieve data from years 2010 to 2014, and start with the list of companies classified as 'no incidents' (excluding merged, absorbed, closed and other non-existing firms). We then filter out companies that belong to a corporate group, as well as companies with zero or negative revenues. Then, in terms of sectoral analysis, PITEC replaces the International Standard Industrial Classification (ISIC) codes with 44 aggregated sectors. Thus, we are interested in the following sectors:

- PITEC code 7 ("wood and cork"), including division 16 of ISIC Rev. 4 and NACE 2009 classification ("Manufacture of wood and of products of wood and cork, except furniture").
- PITEC code 13 ("non-metallic products"), which includes division 23 of ISIC Rev. 4 and NACE 2009 classifications ("Manufacture of other non-metallic mineral products") - basically glass products, clay and ceramic products.
- PITEC code 23 ("furniture"), which includes division 31 of ISIC Rev. 4 and NACE 2009 classifications ("Manufacture of furniture").
- PITEC code 28 ("construction"), which includes divisions 41 to 43 of ISIC Rev. 4 and NACE 2009 classes ("construction of buildings", "civil engineering", and "specialised construction activities", respectively).

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We have not included a series of sectors that are of interest, because the PITEC classification is not detailed enough as to separate them from other sectors. These include PITEC code 10 “Chemicals”, which corresponds to NACE 2009 code 20 “Chemicals”, but includes fertilisers and other agrochemical products. PITEC code 26 “energy and water” includes NACE 2009 codes of electricity, gas, and air conditioning supply, as well as electricity generation and distribution, water collection, treatment and supply. Finally, the NACE 2009 code 71 “Architectural and engineering activities” is hidden in PITEC code 38 “other activities”, which mixes those interesting to us, to others such as NACE 2009 codes 69, 70, 73, 74 and 75 (Legal and accounting, consultancy, advertising, other professional activities, and veterinary activities).

Regarding the variables used, we firstly select some to measure the decision to innovate by the firms. Among the four types of innovation decisions defined by the CIS, we focus on innovation on products and processes in particular:

- Innovation on products, either goods or services (*innprod*).
- Innovation on processes (*innproc*), either in production methods, logistics, or support to processes.

Then, we retrieve a series of variables in PITEC database to measure the determinants of innovation. Following the literature reviewed in Section 2, these are grouped in three domains:

Organisation. It includes internal variables referring to the firm itself, including measures of firm size, and financial resources available.

Technology. It includes external factors referred to the characteristics of the intended innovation. We consider variables of two types:

- Relative advantage: it considers the perceived usefulness (expected improvement, quality, productivity, etc.)
- Cost: it measures the level of resources required to develop the innovation.

Environmental. It includes external factors as well, but related to the social influence: institutional partners and any other sources of information the firms use to innovate.

The list of variables selected are provided in Table 1, available in the next section.

3. MULTIVARIATE STATISTICAL ANALYSIS. RESULTS

Multivariate statistical techniques are useful to explore a large number of variables. Among the techniques available to reduce the number of variables of study we find MCA, PCA and other factorial analyses. PCA helps by reducing the dimensionality of the data, requiring only to interpreting a few components. However, it assumes linear relationships between numeric variables, when most variables in our dataset are categorical. The alternative we use to solve this problem follows [22], a two-step approach that combines MCA and PCA. First, we start from the categorical variables in each domain to make indices for the different domains making use of MCA. Then, we conduct a PCA by making use of the indices, to analyse and interpret the domains ultimately associated with the different innovation decisions.

3.1 Multiple Correspondence Analysis

MCA is a multivariate statistical technique oriented to analyse categorical data. It allows to explore the interdependence between categorical variables when none of them are considered to be dependent or causal, by reducing the dimensionality of the data based on the chi-square distance rather than linear correlations or Euclidean distances [23]. Table 1 provides the list of domains where MCA was applied, separately to each of them. We obtained 10 domains, once the relative advantage of technology was split into five domains – whether the objective is related to growth, improving the quality of products, reducing costs, regulatory compliance, or reducing time response. Moreover, since we traced only one variable in the database as a proxy for the cost of innovation, we include it in “financial restrictions”.

MCA is performed in three steps. First, numerical variables are transformed into quartiles and, for the sake of interpretation, the order of categorical variables coded 1 – 4 in the PITEC database (ascending from 1 = ‘high relevance’ to 4 = ‘not relevant’) are recoded inversely. Only “no partners for cooperation” was not recoded, for coherence within the domain it is included. Second, we use Goodman and Kruskal’s gamma to check whether the variables we assumed to fall within a specific domain are indeed related. All constructs include positively related variables with two exceptions: the variable ‘located in a technological campus’ relate inversely to the other variables in the Social domain, and gross investment in physical goods is coherently inversely related to the variables in the resources domain – since they measure financial restrictions.

Third, MCA is implemented. We determine the MCA dimension whose coordinates are to be used as indicator of each domain. Missing values are replaced by average data. The selected dimension is the one with variables in that specific domain being ranked in a coherent manner – here, always the one with the highest proportion variance explained. We complemented the analysis with a Cronbach’s Alpha, which confirms the internal validity of all constructs. Table 1 provides as well the main descriptive statistics of the dimensions obtained. These are the coordinates to be used in the PCA that follows.

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Table 1: Variables and MCA results – descriptive statistics.

VARIABLE	DEFINITION	type	recoded		MCA	N	Mean	Std. Dev	Min	p25	Median	p75	Max
						Descriptive statistics							
INNOVATION													
Innovation in product / services													
innprod	Innovation in products	dummy 0 - 1		1	INNOPROD	2304	0	0.86	-0.5123	-0.51	-0.51	1.17	2.0824
innobien	Innovation in goods	dummy 0 - 1		1	INNOPROD								
innoserv	Innovation in services	dummy 0 - 1		1	INNOPROD								
Innovation in processes													
innproc	Innovation in processes	dummy 0 - 1		2	INNOPROC	2304	0	0.77	-0.5134	-0.51	-0.51	0.74	2.158
innfabri	Innovation in productive methods	dummy 0 - 1		2	INNOPROC								
innlogis	Innovation in logistics	dummy 0 - 1		2	INNOPROC								
innapoyo	Innovation in support to processes	dummy 0 - 1		2	INNOPROC								
ORGANISATION (internal):													
fim size (employees / capital base)													
revenues	Sales revenues	numerical	ranked by quartiles	3	SIZE	2304	0	0.84	-1.4109	-0.73	0.03	0.71	1.1673
employees	Number of employees	numerical	ranked by quartiles	3	SIZE								
age	Log (# years since the company was launched)	numerical	ranked by quartiles	3	SIZE								
availability of financial resources													
face1	Relevant factors: It has internal financing	categ. 1 ← 4	recoded 1 → 4	4	RESOURCES	2304	0	0.8	-0.5398	-0.51	-0.43	0.19	1.7453
face2	Relevant factors: It has external financing	categ. 1 ← 4	recoded 1 → 4	4	RESOURCES								
inver	Gross investment in physical goods	numerical	recoded as dummy	4	RESOURCES								
TECHNOLOGY (external):													
relative advantage													
objet1	Objective: Wider range of goods / services	categ. 1 ← 4	recoded 1 → 4	5	GROWTH	2304	0	0.52	-1.5395	0	0	0.45	0.5924
objet2	Objective: Substitute products / processes	categ. 1 ← 4	recoded 1 → 4	5	GROWTH								
objet4	Objective: Higher market share	categ. 1 ← 4	recoded 1 → 4	5	GROWTH								
gradcom1	Innomarkt - Objective: Higher market share	categ. 1 ← 4	recoded 1 → 4	5	GROWTH								
objet5	Objective: Greater quality of goods / services	categ. 1 ← 4	recoded 1 → 4	6	QUALITY	2304	0	0.51	-1.4396	0	0	0.15	0.9116
objet6	Objective: More flexibility in production / services	categ. 1 ← 4	recoded 1 → 4	6	QUALITY								
objet7	Objective: Greater capacity in production / services	categ. 1 ← 4	recoded 1 → 4	6	QUALITY								
gradorg3	Innorg - Objective: Greater quality of goods / servs	categ. 1 ← 4	recoded 1 → 4	6	QUALITY								
objet8	Objective: Lower labor costs per unit produced	categ. 1 ← 4	recoded 1 → 4	7	COST	2304	0	0.56	-0.7309	-0.62	0	0	1.2663
objet9	Objective: Fewer materials per unit produced	categ. 1 ← 4	recoded 1 → 4	7	COST								
objet10	Objective: Less energy per unit produced	categ. 1 ← 4	recoded 1 → 4	7	COST								
gradorg4	Objective: Lower unit costs	categ. 1 ← 4	recoded 1 → 4	7	COST								
objet11	Objective: Reduced environmental impact	categ. 1 ← 4	recoded 1 → 4	8	RULES	2304	0	0.66	-0.9195	-0.45	0	0	1.2513
objet12	Objective: Better health / security	categ. 1 ← 4	recoded 1 → 4	8	RULES								
objet13	Objective: Regulatory compliance	categ. 1 ← 4	recoded 1 → 4	8	RULES								
gradorg1	Innorg - objective: Reduced time of response	categ. 1 ← 4	recoded 1 → 4	9	TIME INFO	2304	0	0.37	-0.6683	0	0	0	2.8789
gradorg2	Innorg - objective: Ability to develop new products	categ. 1 ← 4	recoded 1 → 4	9	TIME INFO								
gradorg5	Innorg - objective: Better information exchange	categ. 1 ← 4	recoded 1 → 4	9	TIME INFO								
cost													
face3	Relevant factors: High innovation costs	categ. 1 ← 4	recoded 1 → 4	4	RESOURCES								
ENVIRONMENTAL (external):													
social influence													
parque	Located in a science or technology campus	dummy 0 - 1		10	SOCIAL	2304	0	0.49	-0.8791	-0.07	-0.02	0.07	1.4025
faci4	Relevant factors: No partners for innov. cooperation	categ. 1 ← 4		10	SOCIAL								
fuente5	Information source: consulting	categ. 1 ← 4	recoded 1 → 4	10	SOCIAL								
fuente6	Information source: universities	categ. 1 ← 4	recoded 1 → 4	10	SOCIAL								
fuente7	Information source: public agencies	categ. 1 ← 4	recoded 1 → 4	10	SOCIAL								
fuente8	Information source: technology centers	categ. 1 ← 4	recoded 1 → 4	10	SOCIAL								
fuente9	Information source: conferences	categ. 1 ← 4	recoded 1 → 4	10	SOCIAL								
fuente10	Information source: academic journals	categ. 1 ← 4	recoded 1 → 4	10	SOCIAL								
fuente11	Information source: professional associations	categ. 1 ← 4	recoded 1 → 4	10	SOCIAL								

3.2 Principal Component Analysis

Using the coordinates extracted by the MCA for the 10 indicators in the previous section, we perform a PCA analysis. The purpose of PCA is to explain the variance-covariance structure of a set of variables by creating new, uncorrelated variables, from linear combinations of the original ones. It helps to simplify the analysis: only few components are now required which represent much of the original information, allowing to interpreting the relations among the original variables in a way that might not be obvious with direct observation.

We use the Keiser–Meyer–Olkin (KMO) measure of sampling adequacy, which tests whether the partial correlations among variables are small, and Bartlett's test of sphericity, which tests whether the correlation matrix is an identity matrix. We obtain KMO of 0.770 and a p-value less than 0.001 for the Bartlett's test, what confirms the sample is adequate. We considered four significant components, which account for a cumulated variance higher than 60% for the whole sample. In any case, the main justification for the selection of components is the theoretical interpretability of the results – which we discuss below. For robustness, we performed a varimax

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rotation to the components obtained, in order to get each variable associated with higher loads to a single component. Results are summarized in Table 2. Loadings – the coefficients of each indicator in the linear function of a given component – measure the importance of such variable in the component.

Table 2: Principal component analysis (PCA) factor loadings.

No rotation

	PC1	PC2	PC3	PC4
INNOPROD	0.33	**0.72**		
INNOPROC	0.27	**0.77**		
SIZE		-0.36	**0.74**	
RESOURCES	-0.20	-0.36	**-0.68**	-0.21
GROWTH	**0.79**			
QUALITY	**0.81**			
COST	**-0.82**			
RULES	**-0.85**			
TIME INFO	-0.22	-0.21		**0.91**
SOCIAL	**0.66**			

Varimax rotation

	RC1	RC2	RC3	RC4	h2	u2
INNOPROD		**0.80**			0.65	0.35
INNOPROC		**0.80**			0.67	0.33
SIZE		-0.38	**0.75**		0.72	0.28
RESOURCES		-0.45	**-0.68**		0.68	0.32
GROWTH	**0.80**				0.65	0.35
QUALITY	**0.82**				0.70	0.30
COST	**-0.83**				0.70	0.30
RULES	**-0.87**				0.75	0.25
TIME INFO				**0.95**	0.93	0.07
SOCIAL	**0.68**				0.48	0.52

	PC1	PC2	PC3	PC4
SS loadings	3.393	1.544	1.032	0.962
Proportion Var	0.339	0.154	0.103	0.096
Cumulative Var	0.339	0.494	0.597	0.693

	RC1	RC2	RC3	RC4
SS loadings	3.232	1.662	1.033	1.004
Proportion Var	0.323	0.166	0.103	0.100
Cumulative Var	0.323	0.489	0.592	0.692

Notes: The order of the rotated components (RC) did not change after the rotation. Loadings < |0.2| were omitted for clarity. Proportion Var indicates the variance extracted by each component and u2 the uniqueness of each variable. Variables with a high uniqueness (u2 > 0.5) were marked with the colour off. Bold data (loadings > |0.6|) are highlighted to identify the relevant domains associated with each component.

3.3 Results

Since we deal with four domains (the decisions to innovate, as well as the organisational, technological and environmental determinants), four components were extracted. This way, we also took into account the variance extracted by each component, the total variance extracted, and obtaining a sufficiently low uniqueness of most variables. We obtained two alternative analyses, one for no rotation applied, another for varimax rotation, and results are highly robust.

In summary, the four components account for 69.2% of the total variance. Loadings > |0.6| were highlighted to show which domains are associated with each component. The first component relates the relative advantage of the innovation (including growth, quality, cost and rules) to the social domain. In the none rotation alternative, the objectives to grow and increase quality, as well as having a positive influence from social agents would be weakly related to the decision to innovate. Moreover, reducing costs and regulatory compliance, would have a negative impact. However, none of these results are robust to a varimax rotation.

The most interesting component comes in second instance: the two innovation decisions are grouped in this category, suggesting that product and process innovation tend to come together. Moreover, any relationships between the innovation indicators and other variables with significant loadings within that component are highly meaningful. In our case, we obtain robust results that the variables that are more closely related to the decisions to innovate in sustainable building are the firm size and financial restrictions. In particular, the smaller the firm – in terms of revenues or employees, as well as the younger the company – the more often the companies invest in product or process innovation. Furthermore, firms that exhibit restrictions to access to financial sources – either internal or external – do not innovate. These two are the key factors that determine whether firms in the sector invest in sustainable building.

A third component, which extract about 10% of total variance, reinforces the link between firm size and financial restrictions: as it is frequently observed in the financial literature, age and size are key determinants of a firm's ability to get external financing [24, 25]. Finally, a fourth component includes only the objective to improve the organisation of the company, such as a reduced time of response and better information exchange. We traced no relationship of this indicator with any of the product or process innovation decisions.

4. CONCLUSION

We performed an exploratory analysis to trace the main determinants of firms to invest in sustainable building. Using the PITEC database on information about innovation activities by Spanish firms, we considered the sectors manufacture of products of

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wood and cork, manufacture of other non-metallic mineral products – glass, clay and ceramic products – manufacture of furniture, construction of buildings, civil engineering, and specialised construction activities. We then performed a multivariate statistical analysis based on MCA and PCA combined, to explore the main drivers of innovation by these firms, among a list of 41 indicators in four broad domains, including innovation decisions, organisational, technological and environmental features.

The key result we obtain is that innovation by these firms is related to firm size and financial restrictions: smaller and younger companies invest more frequently in product or process innovation, while firms that exhibit restrictions to access to financial sources do not innovate. Nonetheless, we must emphasize the limitations of this research. Firstly, being an exploratory analysis, we must be aware of the limitations of the statistical techniques used, as well as the sort of variables available in the PITEC database. Secondly, we observed many missing data in the domains related to the relative advantage of technology – such that percentiles 25, 50 (median) and 75 are often filled with the average value of zero (see Table 1). This might be a reason why the exploratory analysis did not trace any relationship of these domains with innovation decisions. To overcome these and other limitations, future research might be based on survey data that allows to getting access to specific data at firm level, as well as including sectors of interest that had to be excluded from this research – such as energy and architecture.

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