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A Counting Multidimensional Innovation Index for SMEs

Introduction

In the European Union, small and medium enterprises (SMEs) are firms employing 10 to 249 employees, which have an annual turnover or an annual balance sheet not exceeding, respectively, €50 million and €43 million (European Commission, 2016).

This research was motivated by several factors, including the importance attached to innovation in the literature; the role of SMEs as major sources of innovation; the need to characterize the innovation of industries dominated by SMEs, such as the metalworking industry in Portugal; and the difficulties in gathering information on SMEs. The main objective of this research is to develop a multidimensional innovation index (MII) framework capable of overcoming the difficulties in measuring and benchmarking innovation of SMEs and groups of SMEs and/or industries, sectors, regions, and countries. The MII framework must be able to generate not only individual SMEs' profiles of innovation, but also individual and group composite indicators. It should also be able to produce results that are aggregated/disaggregated by subgroups of SMEs, by individual indicator and/or by dimension, and by individual SMEs.

Composite indicators have been increasingly used to support data based narratives for political advocacy. However, Saltelli (2007) questioned the simplified messages they provide. Nardo *et al.* (2004), cited in OECD (2008), recommended best practices for the construction of composite indicators. In this research, we follow innovation definitions stipulated by the Organisation for Economic Cooperation and Development (OECD) Oslo Manual (OECD, 2005) and build 20 individual indicators of innovation, adapting suggestions from this Manual and/or individual indicators appearing in the European Innovation Scoreboard (EIS) (Hollanders *et al.*, 2016) and the Global Innovation Index (GII) (Dutta *et al.*, 2016). Hence, the individual indicators being considered in the MII are not new in the innovation literature. The novelty of the MII lies in the counting dual cut-off method employed to establish innovative and non-innovative SMEs, by individual indicator and multidimensionally. This counting dual cut-off method was proposed in the poverty literature by Alkire and Foster (2011), motivated by Atkinson's (2003) discussion of counting methods for measuring multidimensional deprivation, and incorporating Sen's (1993) view of poverty as capability deprivation. The method has been applied to compute the United Nations (UN) Multidimensional Poverty Index (MPI) developed by Alkire and Santos (2010, 2014), and more recently to measure multidimensional poverty in Europe (Alkire and Apablaza, 2016). Thus, the MII framework is based on the method proposed by Alkire and Foster (2011) and has similarities with the UN MPI framework (Alkire and Santos, 2010, 2014). Like the MPI, the MII is based on micro data, employs a counting dual cut-off method that demands individual simple yes/no answers to a set of questions, and is easy to compute.

The remainder of the paper is structured as follows. Section 2 addresses the concept of innovation and the theories behind the OECD Oslo Manual, the EIS, the GII, and the individual indicators of the proposed MII. Section 3 describes the counting dual cut-off method employed to compute the MII, providing an illustrative example. Section 4 outlines an application of the MII framework to SMEs of the metalworking industry in Portugal, presenting and discussing the survey conducted and the results obtained. Section 5 provides the concluding remarks.

Innovation and SMEs

Several theories form the basis for the OECD Oslo Manual, the EIS, the GII, and thus the proposed MII framework. These theories establish the concept of innovation and its relationship with productivity, describe the links between innovation and firm size, discuss the explanatory power of patents, characterize the existence of radical and incremental innovations and of closed innovations (CIs) and open innovations (OIs), identify the territories in which innovation occurs, and many other aspects. They justify the choice not only of the 20 individual indicators used in the MII framework, but also the variables that can be considered *ex post* to explain differences in innovation across SMEs.

The concept of innovation

This research adopts the OECD Oslo Manual's definition of innovation. That is, "An innovation is the implementation of a n   ew or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations" (OECD, 2005, p. 46). The OECD Oslo Manual definition can be traced back to Schumpeter (1934), and is closely related with other innovation definitions appearing in the literature (see, for instance, Joyce *et al.*, 2004; Godin, 2008; and Chauvel, 2011).

Innovations and inventions or creativity are related, but are not the same thing. Inventions necessarily happen before innovations, which explains the attention given in the literature to creativity (Florida, 2002; Landry, 2008; Shearmur, 2012). While creativity refers to the generation of ideas, innovation concerns their implementation. Innovation is a process that transforms inventions into value at the firm level (Lazonick, 2005). Creativity is an important element in innovation (Badawy, 1986). National culture influences economic creativity, and innovation implementation explains some of the variation in prosperity across countries (Williams and McGuire, 2010).

Innovation and productivity

Solow (1956, 1957) noted more than 60 years ago that rising incomes should largely be attributed not to capital accumulation, but to technological progress - that is, to learning how to do things better (Stiglitz, 2014). Technological progress is embodied in neoclassical and new growth theory models (e.g., Romer, 1990), and is highlighted as the principal way in which economic growth can be stimulated (Ray, 1998). However, according to evolutionary and new Schumpeterian approaches, innovation and technological progress is path dependent (Nelson and Winter, 1982; Dosi, 1982; Freeman and Louçã, 2001; Verspagen, 2005).

Concerning the relationship between innovation and productivity in firms, Hall (2011) found an economically significant impact of product innovation and a somewhat more ambiguous impact of process innovation, with the latter result being primarily due to difficulties in measuring the effect. Bloom *et al.* (2012) showed that high management scores are strongly and positively related with countries' development. Bloom *et al.* (2014) provided evidence that an important explanation for the substantial differences in productivity among firms and countries are variations in management practices. Their preliminary estimates suggest that around a quarter to a third of cross-country and within-country total factor productivity (TFP) gaps appear to be management related. Higher management scores are positively and significantly associated with higher productivity, and greater firm size, profitability, sales growth, market value, and chance of survival. Factors such as competition, governance, ownership, human capital, asymmetric information, financial constraints, etc., help to account for the variation in management (Bloom *et al.* 2014). Several authors have analyzed organizational structures and the processes of learning, and adjustment to changes in technology and in the firm environment, including the market (e.g., Lam, 2005).

Many authors have found that the effect of research and development (R&D) on a firm's productivity is positive (e.g,, Lichtenberg and Siegel, 1991; Klette and Johansen, 1998; Harhoff, 1998; Lotti and Santarelli, 2001; Janz *et al.*, 2004; Van Leeuwen and Klomp, 2006; Parisi *et al.*, 2006). Klette and Kortum (2004) have suggested that the returns from R&D have been declining over the years.

Innovation and firm size

Against the Schumpeterian hypothesis of a positive relationship between firm size and innovative activity, a few authors (e.g., Acs and Audretsch, 1988, 1990) have argued that small companies are the engines of technological change and innovation activity. Networks contribute to innovation and performance in SMEs (Gronum *et al.*, 2012), and human capital can have a significant impact in reducing the barriers to innovation represented by knowledge shortages and market uncertainties (D'Este *et al.*, 2014). Small firms provide the most conducive environment for entrepreneurship and innovation, given the commitment and close cooperation of their members (Sahut and Peris-Ortiz, 2014).

Although preliminary, Hall *et al.*'s (2009) results indicate that firm size is negatively associated with R&D intensity and positively associated with the likelihood of having process or product innovations. Revilla and Fernández (2013) studied the effects of firm size on innovative activity using a sample of Spanish manufacturing firms. They found that technological dynamism negatively moderates the effects of firm size on the economic productivity of R&D. Lejarraga and Martinez-Ros (2014) extended the size–innovation debate by proposing that the size of firms affects the scale and quality of product innovation through the adoption of different decision-making styles. Using longitudinal data on Spanish firms, they showed that size is negatively related with the scale and positively related with the quality of product innovation. Antonelli and Scellato (2015) analyzed the effects of the size of the firm in the direction of technological innovations in a panel of 6,600 Italian firms (1996–2005). They found that small firms are more likely to introduce biased technological changes, directed toward the most intensive use of locally abundant production factors, while large firms are more likely to introduce neutral technological changes, and shift the production frontier.

Several authors have addressed the link between innovation and firm growth. According to Audretsch *et al.* (2014), a large number of applied papers have found a positive link between innovation and firm growth. For example, Deschryvere (2014), using Finnish data, found continuous product innovators and occasional process innovators to have the stronger associations between sales growth and subsequent R&D growth.

Innovation and patents

A few studies have questioned the innovation explanatory power of patent citations (e.g., Breschi and Lissoni, 2001; Thompson and Fox-Kean, 2005). Indeed, as pointed out by Acs (2002), the use of patents as an indicator of innovation reveals some problems, such as: (i) patents only register major product innovations; (ii) firms may patent new ideas without having any intention of launching them into the market; and (iii) SMEs may prefer to keep the product secret, and not disclose their inventions.

Radical and incremental innovations

Innovations can be radical or incremental. For Schumpeter (1934), radical innovations cause global changes, while incremental innovations fill in the process of continuous change. For Stiglitz (2014, p.1), "While some of the productivity increase reflects the impact of dramatic discoveries, much of it has been due to small, incremental changes."

A few authors have related radical innovations with networking SMEs and incremental innovations with large and hierarchical organizations operating in markets with few innovations (Freeman and Soete, 1997). Others have related these innovation types with network relationships of firms, with radical innovations requiring strong collaborative ties with customers, while incremental innovations are commercialized through different types of downstream networks (Partanen *et al.*, 2014). Maes and Sels (2014) investigated whether and how internally and externally oriented knowledge capabilities can stimulate radical product innovation in SMEs. They concluded that externally oriented learning processes are dependent on firms' capabilities that increase knowledge diversity and sharing among employees, which in turn has a strong and direct influence as a potential wellspring of radical innovation.

Closed and open innovations

Regarding sources of information, the literature has distinguished CIs and OIs. According to Chesbrough (2003), CIs happen when an organization uses internal sources of information to innovate, such as its own employees, while OIs occur when an organization uses external sources of information to innovate. Chesbrough suggests that many innovative firms have moved to a model of OIs, using a wide range of actors and external sources to help them achieve and sustain innovation.

Laursen and Salter (2006) explored the relationship between the firm's external openness and its innovation performance. The authors found the most open firms to be more likely to get better innovation performance, and the benefits of openness being subject to decreasing returns.

Lasagni (2012) investigated the role of external relationships as key drivers of European SMEs' innovation, and found innovation performance to be higher in SMEs that are proactive in strengthening their relationships with innovative suppliers, users, and customers. Brockman *et al.* (2012) showed that the overall positive influence of customer orientation on SMEs' performance is stronger as risk-taking, innovativeness, and opportunity focus increase. Spithoven *et al.* (2013) studied OI practices in SMEs. They found that the effects of OI practices in SMEs often differ from those in large firms. SMEs are more effective in using different OI practices simultaneously when they introduce new products to the market, whereas this is less true for large firms.

Parida *et al.* (2012) analyzed inbound OI activities in high-tech SMEs. They found technology sourcing to be linked to radical innovation performance, whereas technology scouting is linked to incremental innovation performance.

Barge-Gil (2010) addressed the relationship between the openness of firms' innovation strategies and firm characteristics by distinguishing three firm strategies - open, semi-open, and closed. Using a panel of Spanish firms (2004–2006), he concluded that open innovators are smaller and less R&D intensive than semi-open ones, but larger and more R&D intensive than closed innovators.

Territories in which innovation occurs

Concerning the territories in which innovation occurs, many authors have demonstrated the existence of links between innovation and cities. Bettencourt *et al.* (2007), referring to the number of innovation patents, concluded that the latter occur predominantly in cities. For a few studies, cities are the *loci* of innovation and creativity (e.g., Montgomery, 2007; Florida, 2009). Cohendet *et al.* (2010) studied the anatomy of the creative city by defining three different layers—the upper ground, the middle ground, and the underground. Each one of these layers intervenes, with specific characteristics, in the creative process, and enables new knowledge to transit from an informal micro level to a formal macro level. Shearmur (2012) investigated the correlation between innovation and cities, and argued that cities convert innovation into value, though innovation may occur outside of cities. That is, cities may be dependent on activities that occur in other areas. Shearmur concluded that the only types of innovation specific to cities might be social and political innovations designed to address issues specifically earmarked for housing developments.

Lööf and Johansson (2014) studied the influence of metropolitan externalities on productivity for different types of long-term R&D engagement. They found that firms in Sweden with persistent R&D have a productivity premium that is about 14% in the largest cities and 8% in non-metro locations.

Lee and Rodríguez-Pose (2014) studied the link between local creative industries concentration and SMEs' innovation in the UK. The results suggest that firms in local economies with high shares of creative industries' employment are significantly more likely to introduce entirely new products and processes compared to firms located elsewhere.

Other aspects addressed in the literature

Many other aspects have been addressed in the literature, such as the role of entrepreneurial motivations (Verbees and Meulenberg, 2004; Carsrud and Brännback, 2011), the context dependence of innovation performance (Rosenbusch *et al.*, 2011), the impact and effectiveness of policy support for innovation (Parrilli and Elola, 2012; Foreman-Peck, 2013; Kobayashi, 2014; Castillo *et al.*, 2014; Brancati, 2015), the joint dynamic of export and R&D activities (Esteve-Pérez and Rodríguez, 2013), the impact of the business cycle (Madrid-Guijarro *et al.*, 2013), the family and nonfamily nature of the firm (e.g., Classen *et al.*, 2014), the joint effect of patents and reduced competition (Beneito *et al.*, 2014), the use of CEOs', managers', and nonmanagerial employees' ideas in small firms (Andries and Czarnitzki, 2014), the TFP elasticity with respect to R&D capital (Cchini and Venturini, 2014), the comparison of international innovation strategies of emerging and developed markets (Wang *et al.*, 2014), marketing theories and normative approaches to market exchanges (Hunt, 1983), consumer markets (Burr, 2014), and other aspects.

The EIS and the GII

As part of the Europe 2020 strategy, the European Commission developed the EIS, which, from 2010 to 2015, was called Innovation Union Scoreboard.

The EIS measures and compares the innovation performance of the Member States of the European Union through a composite index called the Summary Innovation Index. To compute the Summary Innovation Index, the measurement framework used in the EIS distinguishes 25 individual indicators, which are classified into three types (and eight dimensions): enablers (human resources, open excellent research systems, finance and support); firm activities (firm investments, linkages and entrepreneurship, intellectual assets); and outputs (innovators, economic effects). Enablers capture the main drivers of innovation performance external to the firm. Firm activities capture the innovation efforts at the level of the firm. Outputs cover the effects of firms' innovation activities (for further details, see Hollanders *et al.*, 2016).

The GII measures and compares the innovation performance of the countries of the world through four composite indices:

- The innovation input sub-index;
- The innovation output sub-index;
- The overall GII score; and
- The innovation–efficiency ratio (IER).

The input sub-index is built around five input pillars or dimensions (institutions, human capital and research, infrastructure, market sophistication, and business sophistication), which capture enablers of national innovative activities. The output sub-index is built around two output pillars or dimensions (knowledge and technology outputs and creative outputs), which capture actual evidence regarding national innovation outputs. Each pillar is divided into sub-pillars and each sub-pillar is composed of individual indicators. The 2016 GII framework distinguishes 82 individual indicators.

The overall GII score is the simple average of the composite input and output sub-indices and the IER is the ratio of the output sub-index and the input sub-index (for further details, see Dutta *et al.*, 2016).

A counting dual cut-off MII for SMEs

Recognizing the existence of outputs and inputs of innovation (see OECD, 2005; Hollanders *et al.*, 2016; Dutta *et al.*, 2016), the MII framework measures and compares the innovation performance of individual SMEs, groups of SMEs and/or industries, sectors, regions, and countries.

Relative to other frameworks, such as, for instance, the EIS and the GII, a first distinctive factor of the MII is that the information collected is strictly SME based. This implies considering only SMEs' innovation outcomes (outputs) and activities (inputs). A second distinctive factor is that it dichotomizes the individual indicators to yes/no answers to a set of questions. This facilitates answering of the questionnaire, obliges the researchers to establish individual indicators of innovation cut-offs, and enables the researchers to better combine quantitative and qualitative information, obtain and more easily interpret individual SMEs' innovation profiles, and better control and interpret the meaning of the composite indices built, namely when the number of individual indicators considered is large. A third distinctive factor of the MII is its well-known mathematical properties and the aggregation/disaggregation and benchmarking possibilities it offers.

The MII vector contains four composite indices, which mimic the four composite indices of the GII:

$$MIIo = Ho \times Ao \quad (1)$$

$$MIIi = Hi \times Ai \quad (2)$$

$$MIIr = MIIo/MIIi \quad (3)$$

$$MIIa = (MIIo + MIIi)/2 \quad (4)$$

The MIIo measures the incidence adjusted by intensity of multidimensional output innovation. The incidence is given by Ho, the percentage of SME's that are multidimensional output innovative. The intensity is given by Ao, the average percentage of dimensions in which multidimensional output innovative SMEs are innovative. The MIIo measure lies on the interval [0,1].

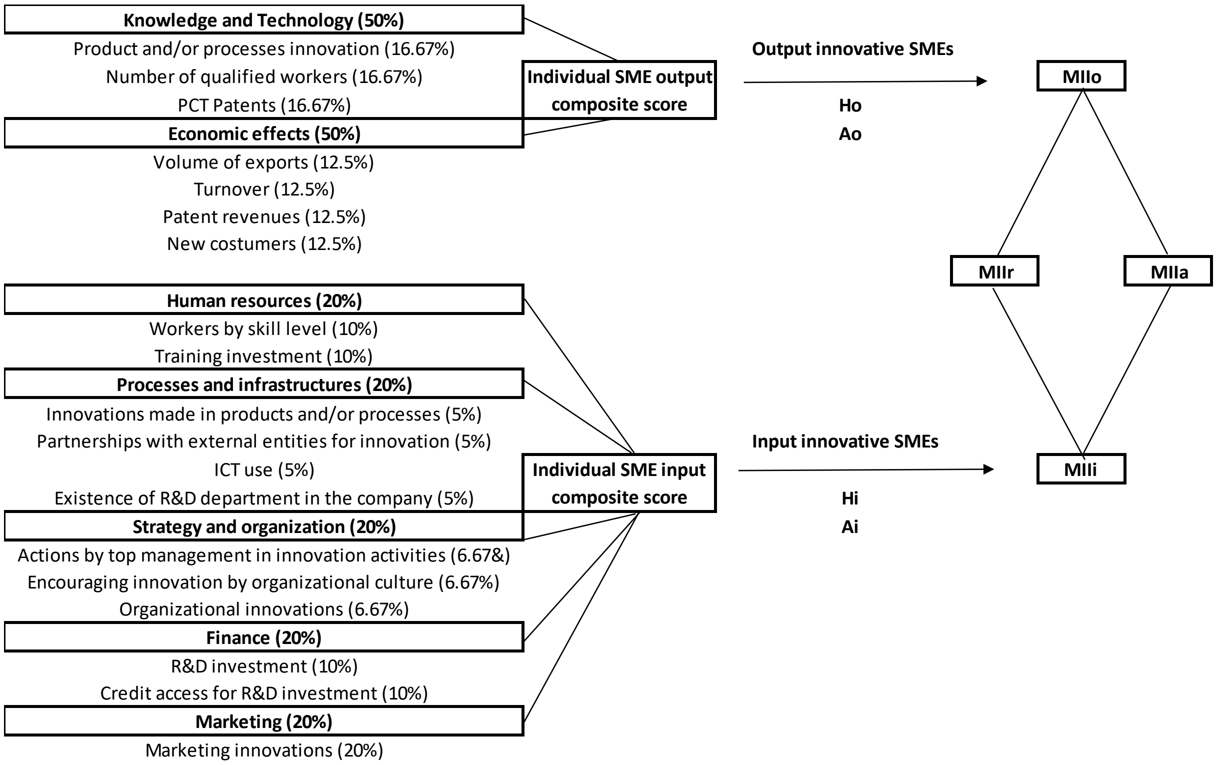
The MIIi measures the incidence adjusted by intensity of multidimensional input innovation. The incidence is given by Hi, the percentage of SME's that are multidimensional input innovative. The intensity is given by Ai, the average percentage of dimensions in which multidimensional input innovative SMEs are innovative. The MIIi measure lies on the interval [0,1].

The MIIr is the ratio between the MIIo and the MIIi. It measures the TFP regarding innovation of the group of SMEs under analysis. The MIIr measure lies on the interval [0, + inf].

The MIIa is the average between the MIIo and the MIIi. The MIIa measure lies on the interval [0,1].

Each individual SME multidimensional output innovation score is built around two output pillars or dimensions (knowledge and technology, and economic effects) covering a total of eight individual indicators. Each separate SME multidimensional input innovation score is built around five pillars or dimensions that correspond to business functions (human resources, processes and infrastructure, strategy and organization, finance, and marketing), covering a total of 12 individual indicators. Therefore, the MII framework distinguishes 20 individual indicators along seven pillars or dimensions. Figure 1 illustrates the MII framework.

Figure 1: The MII framework



Source: Authors

The weights of the dimensions and individual indicators are normative. They do not need to be equal across output (input) dimensions and across indicators in each dimension. The only restrictions are: (i) the sum of the weights of all output (input) dimensions and/or individual indicators must add up to one; and (ii) the sum of the weights of individual indicators in each dimension must add up to the weight of the dimension. Nonetheless, equal weights, for dimensions and for individual indicators in each dimension, facilitate interpretation of the composite indicators (see Atkinson, 2003; Alkire and Foster 2011).

The list of individual indicators and dimensions considered can be altered and/or improved by experts. For instance, it would be possible to have a set of alternative individual indicators that are more suited to addressing SMEs' innovation in developing countries.

As in the MPI (Alkire and Santos, 2010, 2014; Alkire and Apablaza, 2016), the mathematical structure of the MIIo and the MIIi measures corresponds to that of the M_0 poverty measure, with the latter being the adjusted headcount ratio proposed by Alkire and Foster (2011). The M_0 measure has several important properties:

- It is robust when using ordinal or cardinal variables, as it dichotomizes the variables;
- By adjusting multidimensional incidence by intensity, it satisfies dimensional monotonicity;
- It is decomposable by population subgroups; and
- It can be broken down by individual indicator and/or dimension (see Alkire and Foster [2011] for a detailed presentation of the M_0 properties).

Computing the four composite indices of the MII implies the following steps:

1. Establish the set of output and input dimensions and individual indicators to be considered.
2. Set the cut-offs for each individual indicator, above which the SME is considered to be innovative in the individual indicator. These cut-offs are set as 0.5, since all the variables are dichotomized (1 if the SME is innovative in the individual indicator; 0 otherwise), and the MIIo and MIIi cut-offs are also considered as 0.5. Consequently, all individual indicators that are missing values are to be filled with the value of 0.5.
3. Apply the cut-offs to verify in which individual indicators each SME is and is not innovative.

4. Select the relative weights of each dimension and each individual indicator, such that the sum of the weights of all output (input) dimensions or individual indicators adds up to one. As in the MPI, equal weights are chosen for all output (input) dimensions, and for the individual indicators within each dimension.
5. Compute each individual SME multidimensional output (input) innovation score.
6. Determine individual SMEs' multidimensional output (input) innovation cut-off; that is, the proportion of weighted innovation achievements an SME needs to have to be considered multidimensional output (input) innovative. The output (input) cut-off is set to 0.5.
7. Compute the proportion of SMEs that have been identified as multidimensional output (input) innovative in the sample. This is the headcount ratio Ho (Hi).
8. Compute the average intensity score of multidimensional output (input) innovative SMEs, Ao (Ai).
9. Compute MIIo and MIIi.
10. Compute MIIr and MIIa, respectively, as the ratio and the average of MIIo and MIIi.

The cut-offs in step 2 and step 6 are normative. If the cut-offs in step 6 are changed, the cut-offs in step 2 must be changed accordingly, because of the treatment given to the missing values.

To compute the MII, it is only necessary for the group of SMEs under analysis to give yes/no answers to a set of 20 questions corresponding to the 20 individual indicators of innovation being considered. The questionnaire allows building, for each SME under analysis, a profile of innovation using 1s and 0s, which is easy to interpret. It also makes it possible to compute each individual SME's multidimensional output and input innovation scores. Once each SME has been classified as either multidimensional output (input) innovative or non-innovative, the final step is to compute the MII vector that characterizes the group of SMEs under analysis.

Below, an illustrative example of the MII framework is provided based on a group of three hypothetical SMEs: X, Y, and Z. The first step is to fill each SME innovation profile and check whether it is multidimensional output (input) innovative by computing the corresponding multidimensional innovation output (input) score. Table 1 shows the profile of innovation (values of the 20 individual indicators) for each of the three SMEs considered.

Table 1: Innovation profiles of SMEs X, Y, and Z

	Dimension (weight)	Individual indicator (weight)	X	Y	Z
Outputs	Knowledge and technology (50%)	Product and/or process innovations (16.67%)	1	0	0
		Number of workers (16.67%)	1	0	1
		PCT patents (16.67%)	0	0	0
	Economic effects (50%)	Volume of exports (10%)	1	0	1
		Turnover (10%)	1	0	1
		Patent revenues (10%)	0	0	0
		New customers (10%)	1	1	1
		New markets (10%)	1	0	0
Inputs	Human resources (20%)	Workers by skill level (10%)	0	0	0
		Training investment (10%)	1	1	1
	Processes and infrastructures (20%)	Innovations made in products or processes (5%)	1	0	1
		Partnerships with external entities for innovation (5%)	1	0	1
		ICT Use (5%)	1	0	0

		Existence of R&D department in the company (5%)	1	0	0
	Strategy and organization (20%)	Actions by top management in innovation activities (6.67%)	1	1	1
		Encouraging innovation by organization culture (6.67%)	1	1	1
		Organizational innovations (6.67%)	0	0	1
	Accounting and finance (20%)	R&D investment (10%)	1	0	1
		Credit access for R&D investment (10%)	1	0	0
	Marketing (20%)	Marketing innovations (20%)	0	0	1

Source: Authors

From Table 1, the multidimensional output and input innovation scores of SME X are, respectively:

- 1 x 0.1667 + 1 x 0.1667 + 0 x 0.1667 + 1 x 0.1 + 1 x 0.1 + 0 x 0.1 + 1 x 0.1 + 1 x 0.1 = 0.733 > 0.5, for outputs, and
- 0 x 0.1 + 1 x 0.1 + 1 x 0.05 + 1 x 0.05 + 1 x 0.05 + 1 x 0.05 + 1 x 0.0667 + 1 x 0.0667 + 0 x 0.0667 + 1 x 0.1 + 1 x 0.1 = 0.633 > 0.5, for inputs.

It can thus be concluded that SME X is multidimensional output innovative (0.733 > 0.5) and multidimensional input innovative (0.633 > 0.5).

Similar calculations can be performed for SMEs Y and Z. Table 2 shows the multidimensional output and input innovation scores of the three SMEs. Only SME X is multidimensional output innovative; SMEs X and Z are both multidimensional input innovative. SME Y is neither multidimensional output innovative nor multidimensional input innovative.

Table 2: SMEs X, Y and Z multidimensional output and input innovation scores

	X	Y	Z
Multidimensional output innovation score	0.733	0.100	0.467
Is the firm output innovative?	Yes	No	No
Multidimensional input innovation score	0.633	0.233	0.700
Is the firm input-innovative?	Yes	No	Yes

Source: Authors

From Table 2, it is possible to compute the MII vector for the group constituted by the three SMEs:

- MIIo = Ho × Ao = 1/3 × 0.733 = 0.244;
- MIIi = Hi × Ai = 2/3 × [(0.633 + 0.700)/2] = 0.444;
- MIIr = MIIo/MIIi = 0.244/0.444 = 0.550;
- MIIa = (MIIo + MIIi)/2 = 0.244/0.444 = 0.344.

Applying the MII framework to the SMEs of the metalworking industry in Portugal

An online survey was conducted in late 2013 among a universe of 700 SMEs from the metalworking industry in Portugal. The questionnaire asked for information referring to the 2012 fiscal year. A total of 45 SMEs responded, which represents about 6.4% of the firms surveyed.

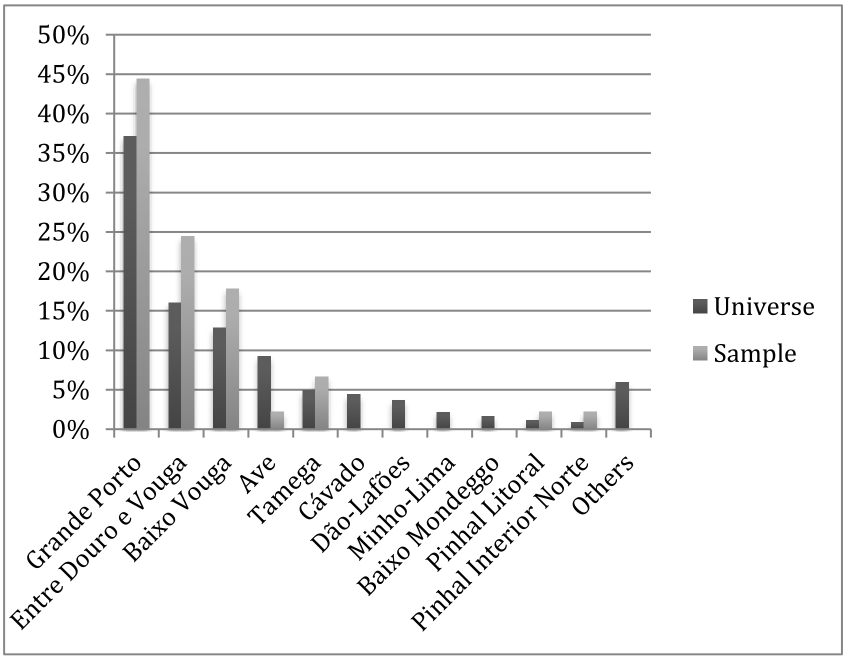
The low response rate is not abnormal for an online survey. The survey was conducted at the end of the fiscal year, which is usually a busy time for companies. The fact that the universe comprises SMEs can also explain the low response rate. A face-to-face pre-pilot test and, subsequently, an online pilot test of the questionnaire were conducted. Once the questionnaire was adjusted, two response requests were made, separated by a three-week period. At each request, SMEs who have previously replied to the questionnaire have been removed.

Sample

Figure 2 and Figure 3 display respectively the distribution of the universe and of the sample by the mainland Portugal level 3 territories of the European Union nomenclature of territorial units for statistics (NUTS 3) and by classes of the Portuguese Classification of Economic Activities (CAE). Table 3 indicates the average scale of operation - that is, number of workers and turnover - of the universe and of the sample. Although the response rate was low, Figures 2 and 3 and Table 3 show the sample to be fairly representative of the universe.

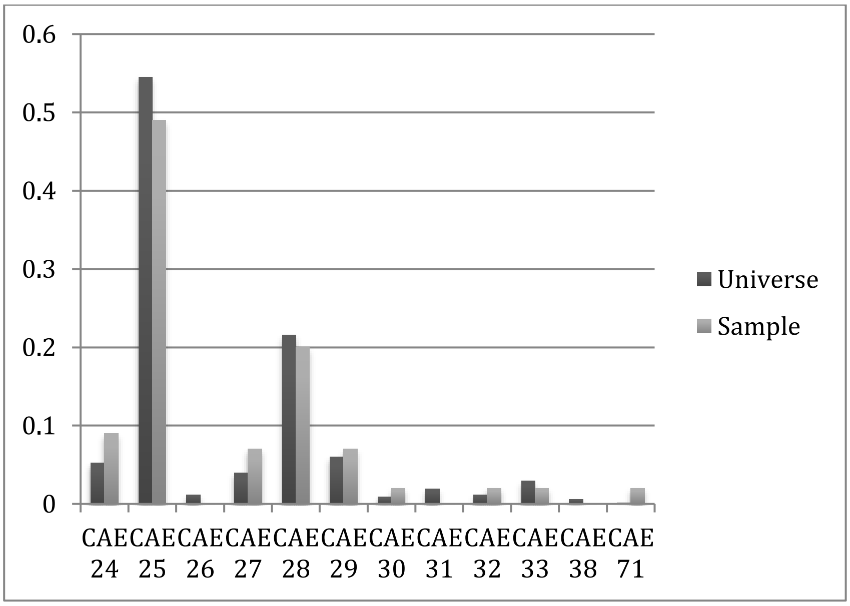
Most of the firms are from “Grande Porto” NUTS 3 and from CAE 25 (“metal products, except machinery and equipment”), in the universe and in the sample (see Table 2A, in the Appendix, for a description of the Portuguese metalworking industry according to the CAE). The average number of workers and turnover are similar in the universe and in the sample.

Figure 2: Universe and sample by NUTS 3



Source: Data provided by the Portuguese metalworking industry association - AIMMAP - and from the authors' survey.

Figure 3: Universe and sample by CAE



Source: Data provided by the Portuguese metalworking industry association - AIMMAP - and from the authors' survey.

Table 3: Average scale of operation in 2012

	Average number of workers per SME	**Average turnover per SME (€)**
Universe	55	5,352,515
Sample	58	5,409,632

Source: Data provided by the Portuguese metalworking industry association - AIMMAP - and from the authors' survey.

Additional characteristics of the sample SMEs are as follows:

- "Exports" (€1,977,193) account for approximately 36.5% of the turnover, while "R&D and innovation expenditures" (€78,095) account for 1.4%, "sales to new markets" (€258,643) for 4.5%, and "sales of innovative products" (€404,591) for 6.5%;
- The average number of "new customers" (11.2) corresponds to 9.1% of the average number of "total customers" (123.3);
- Only two of the 45 sample SMEs have "patents";
- More than 75% of workers are male;
- More than 80% of the workers have a level of education III—that is, "upper secondary education geared for further study at a higher level or less";
- The weight of females in the workforce is superior in intermediate levels of education when compared to other levels, representing half of workers with level IV education—that is, "upper secondary education obtained in basic education courses or dual certification or geared for further studies at a higher level plus internship—minimum of six months";

- The sample SMEs comprise private limited firms, public limited firms, and sole proprietorships. About 64% of the firms are private limited firms;
- About 50% of sample SMEs selected “market share increase,” “production cost reduction,” and “product quality improvement” as motivations to invest in innovation. More than 30% selected “opening new markets” and “producing for the customer” as their motivations. Around 20% selected “obsolete product replacement” and “product range increase.” “Environmental damage reduction” and “maintain market share” did not seem to be major motivations to invest in innovation for most of the firms. The existence of “other motivations” were identified by 5% of the sample SMEs, and “no motivation” by 7%.

MII results

Table 4 provides the proportion of sample SMEs shown to be innovative in each of the 20 individual indicators.

Table 4: Portuguese metalworking industry percentage of innovative SMEs by individual indicator

Dimension	Individual indicator	Percentage of SMEs (%)
Knowledge and technology	Product and/or processes innovations	44
	Number of workers	44
	PCT patents	2
Economic effects	Volume of exports	58
	Turnover	44
	Patent revenues	2
	New customers	62

	New markets	42
Human resources	Workers by skill level	2
	Training investment	82
Processes and infrastructure	Innovations made in products and/or processes	62
	Partnerships with external entities for innovation	44
	ICT use	49
	Existence of R&D department in the company	24
Strategy and organization	Actions by top management in innovation activities	69
	Encouraging innovation by organizational culture	58
	Organizational innovations	51
Accounting and finance	R&D investments	42
	Credit access for R&D investment	9
Marketing	Marketing innovations	31

Source: Authors' survey

Table 5 shows the MII vector composite indices and elements for the sample SMEs.

Table 5: Sample SMEs' MII composite indices and elements

Ho	Ao	MIIo	Hi	Ai	MIIi	MIIr	MIIa
0.289	0.609	0.176	0.422	0.631	0.267	0.660	0.221

Source: Authors

Ho = 0.289; that is, 28.9% of the sample SMEs are multidimensional output innovative.

Ao = 0.609 is the average percentage of dimensions in which multidimensional output innovative SMEs are innovative, that is, 60.9%. Thus, MIIo = Ho x Ao = 0.176 measures the incidence of multidimensional output innovation of the sample SMEs in the interval [0, 1].

Hi = 0.422; that is, 42.2% of the sample SMEs are multidimensional input innovative. Ai = 0.631, showing the average percentage of dimensions in which multidimensional input innovative SMEs are innovative, that is, 63.1%. Thus, MIIi = Hi x Ai = 0.267 measures the incidence of multidimensional input innovation of sample SMEs in the interval [0, 1].

MIIr = MIIo/MIIi = 0.660, which lies in the interval [0, +inf] and corresponds to the TFP of multidimensional innovation of the sample SMEs.

MIIa = (MIIo+MIIi)/2 = 0.221, which lies in the interval [0, 1] and is the average incidence adjusted by intensity of multidimensional output and input innovation of the sample SMEs.

Differences across SMEs

This subsections analyzes the links between individual multidimensional output (input) innovation scores of sample SMEs and other variables used to characterize the sample, which from now on we designate as Z variables. The exercise allows the identification of subgroups of SMEs and to characterize and compare them in terms of innovation by calculating the corresponding MII specific vectors (MIIo, MIIi, MIIr, MIIa).

Available Z variables refer to scale of operation ("number of workers" and "turnover"), the share of exports on the turnover ("export ratio"), classes of economic activity ("CAE #"), the legal nature of the firms ("public limited companies" and "sole proprietorship"), and NUTS 3 territorial location ("Ave," "Baixo Vouga," "Entre Douro e Vouga," "Pinhal Interior Norte," "Pinhal Litoral," "Tâmega"). In the case of qualitative variables, such as CAE, legal nature of the firms, and NUTS 3, dummy variables are used to distinguish each class. NUTS 3 dummy variables capture observable and non-observable effects not captured by the other Z variables taken into account, and are considered for the sake of estimation consistency.

The regression results are presented in Table 6 (see Table A3, in the Appendix, for a description of the data).

Table 6: Explaining the differences in multidimensional innovation across SMEs of the Portuguese metalworking industry

	Individual multidimensional output innovation scores			**Individual multidimensional input innovation scores**		
	Coef.	**Std. Err.**	**P>|t|**	**Coef.**	**Std. Err.**	**P>|t|**
Number of workers	-.0408019	.122759	0.742	.193586	.096073	0.055**
Turnover	-.0125735	.104171	0.905	-.148551	.099224	0.147
Export ratio	.1401962	.139588	0.325	.0717037	.174031	0.684
CAE 24	-.0170588	.064683	0.794	.1831002	.186023	0.344
CAE 27	.1591182	.122838	0.207	.0030383	.194751	0.988
CAE 28	-.1161001	.127532	0.371	-.0400064	.102677	0.700
CAE 29	-.1644721	.134567	0.233	-.1896955	.106404	0.087**
CAE 30	-.0352127	.099223	0.190	-.0761066	.114451	0.635
CAE 32	-.3159792	.110498	0.726	.1422944	.117767	0.225
CAE 33	-.7529799	.138443	0.008*	-.0421088	.10533	0.724
CAE 71	.2873827	.213156	0.000*	-.7507715	.158575	0.000*
Public limited	.117701	.100602	0.253	.0259934	.099050	0.795
Sole proprietorship	.4992659	.139338	0.001*	.5328428	.095483	0.000*
NUTS 3 Ave	.2402359	.115921	0.049*	.1481365	.210758	0.489
NUTS 3 Baixo Vouga	.0368534	.111621	0.744	.0688489	.131679	0.606

NUTS 3 Entre Douro e Vouga	.0785803	.1220637	0.526	.0764345	.1163557	0.517
NUTS 3 Pinhal Interior Norte	-.2149487	.0975117	0.037**	.1206598	.100672	0.242
NUTS 3 Pinhal Litoral	.3185134	.118746	0.013*	.4271834	.109612	0.001*
NUTS 3 Tâmega	-.2268606	.124803	0.081*	-.2134692	.173932	0.231
Constant	.3205571	.095679	0.003*	.327097	.107055	0.005*

*p < 0.01; **p < 0.05, and ***p < 0.10; N = 45; robust estimation.

Source: Authors

Concerning outputs, with a level of significance of 1%, “CAE 33” affects multidimensional output innovation negatively. The effects of “CAE 71” and “sole proprietorship” are positive. In reference to inputs, with a level of significance of 1%, “CAE 71” affects SMEs’ multidimensional input innovation negatively. With a level of significance of 5%, the “number of workers” affects multidimensional input innovation positively, and “CAE 29” has a negative effect. The coefficients of other variables, such as “export ratio” are not significant, although they have the expected signs.

The results of the regressions must be interpreted with caution, given the small size of the sample and of each group of observations. For instance, sole proprietorship corresponds to only two SMEs in the sample (see Table A3 in the Appendix). Nonetheless, they confirm some of the findings of the literature. In particular, the “number of workers” (a measure of scale of operation) has a significant and positive impact on multidimensional input innovation, which supports the Schumpeterian hypothesis of a positive relationship between firm size and innovative activity within the SMEs of the metalworking industry in Portugal. Table 7 distinguishes the MII composite indices for the whole sample, the group of small SMEs (with a number of workers of 10 to less than 50), and the group of medium SMEs (with a number of workers of 50 to less than 250). From Table 7, it is noteworthy that the group of small (medium) SMEs has lower (higher) MII composite indices when compared with the whole sample.

Table 7: Portuguese metalworking industry SMEs' MII composite measures

	Whole sample	Small SMEs (10 to < 50 workers)	Medium SMEs (50 to < 250 workers)
MIIo	0.176	0.122	0.308
MIIi	0.267	0.192	0.449
MIIr	0.660	0.636	0.686
MIIa	0.221	0.157	0.404

Source: Authors

Conclusions

This research was motivated by several factors, including the importance attached to innovation in the literature; the role of SMEs as major sources of innovation; the need to characterize the innovation of industries dominated by SMEs, such as the metalworking industry in Portugal; and the difficulties in gathering information on SMEs.

We developed a counting dual cut-off MII framework to measure and benchmark the innovation performance of individual SMEs and groups of SMEs and/or industries, sectors, regions, and countries. The MII framework follows the methodology of the United Nations Multidimensional Poverty Index and the innovation definitions stipulated by the OECD Oslo Manual, adapting individual indicators suggested by this Manual and/or appearing in the EIS and in the GII. The MII framework generates a vector with four composite indices characterizing the group of SMEs under analysis: MIIo and MIIi measure, respectively, the incidence of multidimensional innovation in terms of outputs and inputs, while MIIr and MIIa assess, respectively, the ratio and average of MIIo and MIIi.

Relative to other frameworks, such as, for instance, the EIS and the GII, a first distinctive factor of the MII is that the information collected is strictly SME based. A second distinctive factor is that it dichotomizes the individual indicators to yes/no answers to a set of questions. A third distinctive factor of the MII is its well-known mathematical properties and the aggregation/disaggregation and benchmarking possibilities it offers.

To illustrate the MII framework, a survey was conducted among SMEs of the metalworking industry in Portugal. In 2012, about 29% (42%) of these SMEs were multidimensional output (input) innovative. The average percentage of dimensions in which multidimensional output (input) innovative SMEs were innovative was 60.5% (63.3%). Thus, the industry MII vector was [MIIo; MIIi; MIIr; MIIa] = [0.175, 0.267, 0.654; 0.221].

Significant differences were found across SMEs of the industry in relation to their individual multidimensional innovation output and input scores. These differences can be explained by factors such as the number of workers, class of economic activity, and legal status, and they facilitate identification of groups of SMEs in the industry, which can be characterized and compared in terms of innovation by computing the corresponding and specific MII vectors. This exercise was conducted for the sample groups of SMEs. When compared with the whole sample, the group of small (medium) SMEs has lower (higher) MII composite indices, which supports the Schumpeterian hypothesis of a positive relationship between firm size and innovative activity within SMEs of the industry.

There are several issues to address in future research. Experts can adjust the set of individual indicators of innovation considered. The weights and the cut-offs of the counting dual cut-off method employed are normative, and can also be adjusted by experts. These changes do not alter the nature and the properties of the counting dual cut-off method employed to measure multidimensional innovation of individual SMEs and groups of SMEs and/or industries, sectors, regions, and countries.

The analysis carried out on the SMEs of the Portuguese metal working industry was limited by the small sample size. In addition, the MII framework should be further tested on SMEs of other industries and countries, namely developing countries.

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APPENDIX

Table A1: MII individual indicators

Individual indicators
Outputs, knowledge, and technology
1. Product and/or process innovations. Company's ability to introduce innovations in products and processes in their markets. **2. Number of workers.** Company's ability to increase its number of qualified employees. **3. PCT patents.** Company's ability to create patents, since the company's ability to develop new products will determine its competitive advantage, and is therefore a good indicator of the innovation rate in new products.
Outputs, economic effects
4. Volume of exports. Company's ability to increase its volume of exports. **5. Turnover.** Company's ability to increase its turnover. **6. Patent revenues.** Company's license and patent revenues. **7. New customers.** Company's ability to obtain new customers. **8. New markets.** Company's ability to enter into new markets.
Inputs, human resources
9. Workers by skill level. Degree of qualification of employees in the company, and percentage of those with master's or doctoral qualification. **10. Training investment.** Company's investment in the training of employees.
Inputs, processes, and infrastructure
11. Innovations made in products and/or processes. Company's internal innovation achievements in its products and/or processes. **12. Partnerships with external entities for innovation.** Degree of company's involvement with external entities for innovation.

13. ICT use. Company's use of computer tools or specialized software during the process of manufacturing and services. **14. Existence of R&D department in the company.** Presence (or lack) of exclusive space dedicated to R&D within the company's facilities.
Inputs, strategy, and organization
15. Actions by top management in innovation activities. Top management's degree of active participation in the innovation process. **16. Encouraging innovation by organizational culture.** Extent to which company's culture encourages entrepreneurship, and the risk-taking behavior of its workers. **17. Organizational innovations.** Company's ability to innovate organizationally, according to the defined concept of organizational innovation.
Inputs, finance
18. R&D investment. Company's financial efforts in R&D. **19. Credit access for R&D investment.** Company's ability to obtain external financing to invest in R&D.
Inputs, marketing
20. Marketing innovations. Extent of company's innovations in marketing in accordance with the stipulated definitions.

Source: Authors

Table A2: Description of the Portuguese metalworking industry CAE

CAE #	Description
CAE 24	Manufacture of basic metals.
CAE 25	Manufacture of fabricated metal products, except machinery and equipment.
CAE 26	Manufacture of computer equipment, communications and electronic and optical products

CAE 27	Manufacture of electrical equipment.
CAE 28	Manufacture of machinery and equipment.
CAE 29	Manufacture of motor vehicles, trailers, semi-trailers, and components for motor vehicles.
CAE 30	Manufacture of other transport equipment.
CAE 31	Manufacture of furniture and mattresses
CAE 32	Other manufacturing industries.
CAE 33	Repair and installation of machinery and equipment.
CAE 38	Collection, treatment and disposal of waste; Improvement of Materials.
CAE 71	Activities architectural, engineering, and related techniques; activities of testing and analysis techniques.

Source: INE (2007)

Table A3: Description of regression variables

Output multidimensional innovation score	**Input multidimensional innovation score**	**NUTS 3 #[a]**	**CAE #[b]**	**Number of hundreds of workers**	**Turnover (in 10 million euros)**	**Export Ratio**	**Legal Status[c]**
0.6334	0.7334	3	28	0.47	0.4577886	0.41	2
0.8001	0.6334	2	25	0.18	0.075926389	0.32	2
0.7001	0.4667	4	25	0.11	0.0622335	0.03	2
0.1667	0.3667	2	25	0.24	1.5	0.10	2
0.4834	0.4334	2	25	0.16	0.12	0.01	2
0.1	0.3	3	25	0.06	0.515191284	0.35	2

0.3	0.3	3	25	0.55	0.515191284	0.35	2
0.1667	0.2167	3	28	0.16	0.515191284	0.35	2
0.5501	0.4	4	25	0.3	0.36	0.70	2
0.2334	0.1	4	25	0.1	0.036	0.00	2
0.1834	0.1	4	29	0.23	0.19	0.00	2
0.8501	0.7334	4	28	0.12	0.075	0.25	3
0.5334	0	4	28	2.11	0.515191284	0.35	1
0	0.2	7	25	0.53725	0.515191284	0.35	2
0.6501	0.3667	4	24	0.06	0.515191284	0.35	2
0.15	0.3334	4	25	0.19	0.2	0.25	2
0.4334	0.1667	3	28	0.53725	0.515191284	0.35	2
0.2834	0.4667	4	29	1.02	0.5	0.96	1
0.4001	0.1667	2	25	0.36	0.17	0.53	2
0.76675	0.6334	1	24	0.78	0.7362103	0.93	2
0.4001	0.3667	7	27	0.14	0.515191284	0.35	2
0.5834	0.4667	2	24	1	0.50951	0.57	1
0	0	7	28	0.2	0.2470774	0.57	1
0.1	0.1	4	33	0.22	0.515191284	0.35	3
0.8001	0.7334	3	25	1.7	1.2	0.40	1
0.5084	0.4667	4	30	0.16	0.3783171	0.53	1
0	0	4	25	0.13	0.0230658	0.00	2
0.5501	0.7334	4	25	0.53725	0.515191284	0.35	2
0.5001	0.6834	2	27	1.3	0.7	0.11	1
0.3501	0.1	4	32	0.14	0.095893343	0.73	2
0.2834	0.4167	3	25	0.9	0.619872871	0.17	1
0.1	0	3	25	0.24	0.515191284	0.35	2
0.71675	0.3667	3	28	0.7	0.543006667	0.20	1
0.13335	0.38335	2	27	0.07	0.515191284	0.35	2

0.6834	0.5667	2	25	0.55	0.679	0.85	1
0.2834	0.5167	4	28	0.1	0.039	0.26	2
0.36675	0.35	4	28	0.56	0.515191284	0.35	1
0.4834	0.1	5	25	0.36	0.271633476	0.09	2
0.4167	0.4667	4	25	0.16	0.1134	0.04	1
0.4667	0.1	4	29	3.44	2.95	0.47	1
0.8001	0.6334	6	25	1.19	1.4522446	0.44	2
0.750	0.6334	3	25	0.11	0.079313596	0.10	2
0.5	0.533	4	71	2.72	1.75	0.35	2
0.2	0.3	4	25	0.08	0.515191284	0.35	2
0.6501	0.6334	3	25	0.95	0.6353672	0.13	1

Notes: The regression considered dummy variables for CAE, legal status, and NUTS 3 classes.

[a] 1 = Minho-Lima; 2 = Cávado; 3 = Ave; 4 = Grande Porto; 5 = Tâmega; 6 = Entre Douro e Vouga; 7 = Douro; 8 = Alto Trás-os-Montes; 9 = Baixo Vouga; 10 = Baixo Mondego; 11 = Pinhal Litoral; 12 = Pinhal Interior Norte; 13 = Pinhal Interior Sul; 14 = Dão-Lafões;15 = Serra da Estrela; 16 = Beira Interior Norte; 17 = Beira Interior Sul; 18 = Cova da Beira; 19 = Oeste; 20 = Grande Lisboa; 21 = Península de Setúbal; 22 = Médio Tejo; 23 = Lezíria do Tejo; 24 = Alentejo Litoral; 25 = Alto Alentejo; 26 = Alentejo Central; 27 = Baixo Alentejo; 28 = Algarve.

[b]See Table A2 for CAE description.

[c]Legal status: 1 = Private limited firms, 2 = Public limited firms, 3 = sole proprietorship.

Source: Authors