Spatial autocorrelation of exports and R&D expenditures in Portugal*

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Abstract

This article analyzes spatial autocorrelations and the formation of clusters of exports, based on Research and Development (R&D) intensity in Portugal. The central idea is that exports show relative interdependence and spillover effects among nearby regions and a direct relationship with R&D expenditures. It adopts the new taxonomy of the OECD, separating exports by manufacturing and non-manufacturing activities. Methodologically, is was used Exploratory Spatial Data Analysis (ESDA), utilizing Global Moran's Index and LISA. The results showed the presence of positive spatial autocorrelation of exports and the formation of a cluster of the High-High type for the Porto metropolitan region and Aveiro region. There was no confirmation of positive spatial autocorrelation for R&D expenditures among the regions of Portugal. However, there was both a positive spatial autocorrelation for exports associated with R&D expenditures as well as the formation of a regional cluster with high-high pattern for the Aveiro region. This outcome can be explained, in part, by nationally and internationally recognized universities and research centers surrounding the region, favoring knowledge spillovers across the regions.

Keywords: Export; R&D expenditures; Spatial autocorrelation; Technological intensity; Clusters; Spillovers; Portugal

JEL Codes: F10, F14, O32, R12.

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1. Introduction

The ‘new theory of international trade’ argues that the world is more economically globalized, financially and commercially, making productive efficiency an increasingly determinative factor. In this context, technology gains importance, contributing to an increased competitiveness and, consequently, an improved international position of each nation-sate. Some works have shown that the relationship between technology and international trade is relevant to a state's becoming or remaining competitive in the international scene (Fagerberg, 1988; Krugman, 1990; Archibugi and Michie, 1998; Nonnemberg, 2013; Altomonte et al., 2016; Rebelo and Silva, 2017) and promoting its economic growth (Herzer, Nowak-Lehmann and Siliverstovs, 2006; Ribeiro, Carvalho and Santos, 2016).

In this process of economic growth, countries and regions have shown distinct dynamics, with visible asymmetries among them, whether in the economic or technological dimension (Krugman, 1990; Guarascio, Pianta and Bogliacino, 2016; Kontolaimou, Giotopoulos and Tsakanikas, 2016). According to Dosi, Pavitt and Soete (1990), these international asymmetries that arise over time, especially in the technological aspect, determine international trade flows and their patterns of specialization. Therefore, the countries and regions that have an export portfolio based on technology-intensive products, with regional environments more favorable to innovation, have better conditions to maintain and increase their competitiveness (Dosi, Pavitt and Soete, 1990; Archibugi and Michie, 1998; Jensen et al., 2007; Gama, Barros and Fernandes, 2018; Melo et al., 2017; Segarra-Blasco, Arauzo-Carod and Teruel, 2018). In fact, firms that are located closer to knowledge innovate more quickly than those farther away, since they can absorb knowledge through the circulation of ideas that come from direct contact among economic agents (Baptista, 1999; Storper and Venables, 2004; Fritsch and Kauffeld-Monz, 2010; Lambooy, 2010). Baptista (2000) argues that the externalities that promote the adoption of new technologies are more important at the regional level and depend positively on the proximity of firms that can use them. Adding to this, Basile Capello and Caragliu (2012) show that social and relational proximity are important channels for the dissemination of knowledge externalities and that, when simultaneously present, different types of proximity generate synergistic effects on growth.

It is therefore assumed that the intensity of the relationship among economic agents decreases as the distance among them increases. However, these relationships are not limited by administrative boundaries, which means that externalities resulting from the association between R&D activities and export-producing activities can cross these boundaries (Coe and

Helpman, 1995; Eaton and Kortum, 1996; Guastella and van Oort, 2015). Therefore, spatial interactions must be considered (Quah, 1996) when analyzing economic and technological relationships among the agents. Consequently, it is important to study the location of exporting and R&D activities to investigate whether there is a pattern of regional concentration for each of these activities and, if so, whether there is a relationship between the two patterns. Nonetheless, little attention has been dedicated to spatial dependency within nations (López-Bazo and Montellón, 2018). It is in this sense that the present study contributes to the current debate by analyzing the formation of spatial clusters of export-producing activities, by technological intensity, and R&D expenditures among the Portuguese regions and the existence of a pattern of spatial autocorrelation within these activities.

Recent works have shown regional differences in Portugal, revealing a degree of spatial heterogeneity, with productive activities and income generation concentrated in the regions of Lisbon and Porto (Freitas and Mamede, 2010; Vaz et al., 2014; Machado, 2019). These differences are the result of institutional profiles related to innovation in the regions (Vaz et al., 2014). It is also worth noting that Portugal is a country of relatively small economic size, regionally concentrated, open and peripheral in relation to its bloc and, therefore, has particular features - though similar to those of many European Union countries (Neves, Teixeira and Silva, 2016; Ribeiro, Carvalho and Santos, 2016) -, and is assigning an increasingly important role to exports in its process of economic development (Herzer, Nowak-Lehmann and Siliverstovs, 2006; Ribeiro, Carvalho and Santos, 2016; Machado, 2019).

Based on this context, regions with a higher concentration of exports, with institutional environments more capable of generating knowledge and innovation, are expected to show a strong capacity for formation of spatial clusters. In addition, a positive spatial autocorrelation is expected between R&D expenditures and exports capable of regional spillovers beyond their administrative limits, generating distinct dynamics among sets of regions.

This work aims to analyze the spatial autocorrelation and cluster formation of exports, by technological intensity, associated with R&D expenditures in Portugal. The methodology uses export data, by NUTS III regions of Mainland Portugal, classified by level of technological intensity, based on Galindo-Rueda and Verger (2016), that distinguishes manufacturing and non-manufacturing activities. The use of this classification makes the work unprecedented since the most research has considered only manufacturing activities classified by groups of technological intensity. The paper uses spatial econometrics, based on Exploratory Spatial Data

Analysis (ESDA), notably the method of spatial autocorrelation, by means of Moran's I (univariate and bivariate) and LISA (Local Indicators of Spatial Association).

The paper is organized in five sections, besides this introduction and the final conclusions. The second section presents a brief evolution of the approach to international trade, emphasizing especially the relationship between innovation and international trade. The third section details the methodology, describing the data source, its treatment and the aspects related to spatial autocorrelation (Moran's I and LISA). The fourth section analyzes and discusses the results to show the pattern of spatial distribution and the formation of clusters of Portuguese exports, by groups of technological intensity in the studied period, as well as their spatial relationship to R&D expenditures. Finally, the discussion and conclusion are presented, highlights the main points of the work and considers the possibility of proposing more specific policies to support countries with similar characteristics.

2. International trade and technology: Theoretical and empirical review

Technology is becoming one of the most important factors to explain the profile of global trade flows, while the technological performance of each country has become a modeler of international competitiveness. Therefore, the debate regarding the international competitiveness of a country or a region is concerned with explaining the role of innovation and of technological advances in its economic performance (Fagerberg, 1996; Archibugi and Michie, 1998). The discussion between technology and trade emerges from the North-South models and the Technology Gap of Krugman (1985 & 1990), in which the patterns of trade arising from the technological gaps and the different technological intensities of various products are shown to be a fundamental force which shapes countries' comparative advantages. However, both models assume that technical progress is exogenous.

In a microeconomic approach, many ‘more endogenous’ aspects of technology are considered, which are the result of the allocation of resources to R&D and the nature of knowledge spillovers (Fagerberg, 1988 & 1996; Dosi, Pavit and Soete, 1990; Capello and Lenzi, 2015). The resources applied to R&D affect the trade patterns, since the countries that invest more are those more likely to specialize in high-tech industries, with faster growth prospects (Dosi, Pavitt and Soete, 1990; Grossman and Helpman, 1991; Braja and Gemzik-Salwach, 2019). Therefore, international differences in technological levels and in innovative capacities are key factors in explaining the evolution of exports (Dosi, Pavitt and Soete, 1990) and, consequently, the specialization pattern. Consequently, growth in productivity and in R&D expenditures, are also related to an increase in market share in international trade (Fagerberg, 1996; Guarascio, Pianta and Bogliacino, 2016; Altomonte et al., 2016).

The literature considering the role of technology and innovation in international trade suggests that comparative advantages can be created and maintained through investment in technology and knowledge (Altomonte et al., 2016; López-Bazo and Motellón, 2018)[1]. Thus, the absolute advantages of a country, whether in terms of costs or of technology, are the driving forces of the adjustment process. On this view, the technological differences among countries emerge as the central element of economic analysis, given that the explanations of the technological gaps in the trade flows represent the impact of different absolute advantages in competitiveness (Rosemberg, 1982; Fagerberg, 1988; Dosi, Pavitt and Soete, 1990; Verspagen and Wakelin, 1997; Melo et al., 2017; Raiher, Carmo and Stege, 2017).

The evolutionary approach considers technology and the innovative process as essential sources of economic growth and development, which affect the nature of technological and commercial competition as well as the industry standards and the industrial organization of the innovative activity of firms, regions and countries (Verspagen and Wakelin, 1997; Cainelli, Di Maria and Ganau, 2016). It is from this perspective that studies begin to assign an important role to regional spaces in the generation and dissemination of knowledge for the innovative process (Krugman, 1991; Audretsch and Feldman, 2004; Jensen et al., 2007; Segarra-Blasco, Arauzo-Carod and Teruel, 2018). Therefore, an attempt was made to highlight the attributes of location, taking into account the knowledge (basis of innovation), involved in the individuals, businesses and institutions (especially those of teaching and research), as well as its channels of regional spillovers (Audretsch and Feldman, 2004; Capello and Lenzi, 2013) and the role of agglomeration effects and the resulting knowledge externalities, with their impact on firms' productivity (Guastella and van Oort, 2015; Altomonte et al., 2016; Cainelli, Di Maria and Ganau, 2016; Carreira and Lopes, 2017; Segarra-Blasco, Arauzo-Carod and Teruel, 2018).

Attempts have been made to highlight the innovative dynamics and the regional disparities (Capello and Lanzi, 2015; Guastella and van Oort, 2015), but also to reveal the regions characterized by a greater process of agglomeration of economic activities that also have a set of institutional assets[2], especially with universities and research centers capable of generating

[1] Readers interested in the origins of this discussion can refer to the work of Posner (1961).
[2] Similar to the national and regional innovation systems (Lundvall, 1992; Freeman, 1992; Edquist, 1997; Edquist and Johnson, 1997; and Cimoli and Della Giusta, 1998).

and transmitting knowledge beyond its region (Elvekrok, et al., 2018; Zhou, Zhu and He, 2019). Thus, firms look for clusters where there are institutional elements that generate knowledge to produce innovation. So economic performance depends on the endogenous institutional and cultural characteristics which, will lead to gains in productivity, determined by the stock of knowledge and innovation, differentiated among the regions (Audretsch and Feldman, 2004; Vaz et al., 2014; Faustino and Matos, 2015). Baptista and Mendonça (2010), using data from Portuguese municipalities for the period 1992–2002, estimate the effects of the creation of new universities on the firms entry in different sectors and municipalities. They conclude that a new university has a positive effect on the entry of knowledge-based firms and a negative effect on the other sectors like low-tech manufacturing. Thus innovation, a source of competitiveness, can occur in different ways, revealing patterns[3] being dependent on the stock of regional knowledge and its spillover channels (Capello and Lenzi, 2015). This generates a virtuous circle in the firms and regions that starts on R&D investments, which increases productivity and exports and promoting new investments in a progressive and lasting manner (Neves, Teixeira and Silva, 2016).

The use of exports data level of technological intensity for manufacturing and non-manufacturing industry is also relevant. In fact, according to Herzer, Nowak-Lehmann and Siliverstovs, (2006), exports of manufacturing industry products have positive effects on growth, unlike exports of primary sector products which have negative effects. In addition, according to the endogenous growth theory, the greater the technological intensity content of exports, the greater the positive externalities for other sectors (Herzer and Nowak-Lehmann, 2006).

In this context, our first hypothesis is that the metropolitan areas of Lisbon and Porto (with greater relative participation in exports) form spatial clusters. Being high-tech activities, greatly dependent on scientific and technological knowledge, they seek out local contexts with greater knowledge stock, that therefore are associated with the presence of universities and research centers that support and contribute to their intensive R&D activities (Freeman, 1988; Lundvall, 1992; Etzkowitz and Leydesdorff, 2000; Jensen et al., 2007, Capello and Lenzi, 2015; Gama, Barros and Fernandes, 2018; Segarra-Blasco, Arauzo-Carod and Teruel, 2018). Our second hypothesis is that there is spatial autocorrelation between exports and R&D expenditures among

[3] Capello and Lenzi (2013) developed a typology which divides the innovative process into three patterns: Endogenous innovation in a scientific network; Creative application (seeking knowledge outside the region); and Imitative innovation (diffusion).

the regions of Portugal. In fact, innovative efforts are often identified as determinants of exports – and vice versa (Neves, Teixeira and Silva, 2016) – and, at the same time, the formation of spatial clusters, based on concentration patterns and regional spillovers (Fagerberg, 1996; Archibugi and Michie ,1998; Audretsch and Feldman, 2004; Altomonte et al., 2016; López-Bazo and Motellón, 2018).

Despite the published studies associating technology, productivity and economic growth, there is still little knowledge about the relationship between the location of economic activity, namely exports, and the levels of technological intensity. Thus, this study analyzes exports associated with their technological effort (R&D), recognizing the importance of productivity in this context, as well as the different levels of technological intensity present in certain segments at the regional level in Portugal. Additionally, the work recognizes the importance of space and its attributes, both internal and institutional, as well as the possibilities of regional spillovers, which imply progressive trajectories of economic growth and development.

3. Empirical methodology

3.1. Database

The source of export data was the National Statistical Institute of Portugal (INE). These data were organized by the Combined Nomenclature Classification (NC2), by sections and, more disaggregated, by divisions. The classification by technological intensity is organized using the Classification of Economic Activity (CAE Rev. 3), which is equivalent to the statistical classification of products by activities in the European Community, version 2.1 of 2019 (CPA 2.1)[4]. Thus, a correspondence was established between 2019 NC2 and CAE Rev. 3. Even so, since the data available in NC2 are disaggregated to two digits, it was necessary to make some adjustments between the classification, which are found in the explanatory note in Appendix B in the supplementary data. The values of the exports were available in Euros and deflated by the price index of industrial production in the domestic market by economic activity (CAE Rev. 3), with its base changed to the year 2011. After this, a natural logarithm was applied to reduce any discrepancies among the data.

[4] To classify the export data by technological intensity, a correspondence table between 2019 NC2 and CPA 2.1 was used. The correspondence table is available at: http://smi.ine.pt/Correspondencia. (NC 2019 x CPA 2.1 correspondence table – International Trade. TC00814 - NC 2019 - CPA 2.1 - international trade).

The classification by technological intensity follows the new taxonomy of the OECD (Galindo-Rueda and Verger, 2016), which divides economic activities into five groups of technological intensity, considering manufacturing and non-manufacturing activities: High, Medium-High, Medium, Medium-Low and Low technological intensities[5]. This is an original contribution of the article, since, as far as is known, there are no works using this classification. For a better understanding of the studied phenomenon, the Medium-Low technological intensity group was split in two: Medium Low with Manufacturing sectors (MLM) and Medium-Low with Non-Manufacturing sectors (MLNM). In addition, the High (HM), Medium-High (MHM) and Medium (MM) intensities are made up only of Manufacturing sectors. Low technological intensity, however, was restricted to Non-Manufacturing activities (LNM)[6]. Annual R&D spending was collected from the INE Portal (2019) and refers to the R&D of institutions and companies by geographical location (NUTS - 2013), for the period from 2011 to 2017. The values were available in Euros and deflated by the same price index used for exports, followed by application of the natural logarithm. From a spatial point of view, the 23 NUTS III regions of Continental Portugal were used (version of 2013).

3.2. Exploratory Spatial Data Analysis (ESDA)

More recent studies have been concerned with showing the relationships that can occur among regions, emphasizing the importance of spatial proximity (Almeida, Perobelli and Ferreira, 2008; Vogel and Azevedo, 2015; Cainelli, Di Maria and Ganau, 2016; Raiher, Carmo and Stege, 2017; Machado, 2019)[7]. Empirical studies that examine the possibility of dependence among regions use the econometric technique of Exploratory Spatial Data Analysis (ESDA), which is based on the spatial aspects contained in the database (Anselin, 1988; Florax, Folmer and Rey, 2003; Almeida, Perobelli and Ferreira, 2008; Gonçalves, 2007; Cainelli, Di Maria and Ganau, 2016). The objective of this method is to characterize the spatial distribution and the patterns of spatial association (spatial clusters), to verify the presence of different spatial arrangements or other forms of spatial instability (nonstationarity) and to identify outliers.

[5] The classification table used is found in Appendix D in the online supplementary data.
[6] This was due to the fact that no correspondence was found in such activities between the 2019 NC2 and CAE Rev. 3.
[7] Implicitly or explicitly, these studies assume the First Law of Geography, called 'Tobler's Law', central idea of which is: 'Everything is related to everything else, but near things are more related than distant things' (TOBLER, 1970, p. 236).

According to Anselin (1988), spatial econometrics considers two spatial effects: spatial dependence or spatial autocorrelation and spatial heterogeneity. These two effects tend to be ignored in the conventional econometrics' literature, most likely because of the emphasis on dynamic phenomena and time series data (Anselin, 1988). The spatial dependence is given by the interaction of agents in space, that is, the value of a variable in a certain region *i* depends on the value of this variable in the neighboring regions *j*. The notion of spatial dependence or spatial autocorrelation is defined by Florax and Nijkamp (2003) as spatial clusters of similar values, common patterns or systematic spatial variations; that is, a characteristic of the probability density function, verifiable only under certain simple conditions, such as normality. In this sense, the best spatial statistical association for ordinary data in intervals is given by Geary's C and Global Moran's I. The two are similar but based on different metrics. According to Feser and Isseman (2005), Moran's I is more commonly applied in regional analyses. Anselin (1996) proposed a tool to visualize the instability of spatial global autocorrelation, via the dispersion of Moran's I. The procedure is performed via a linear regression, where the coefficient is I, which indicates the degree of spatial relation of the variables. Its definition in univariate form is given by the following equation:

$$\mathrm{I} = \frac{n}{S_0}\left(\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right) \qquad (1)$$

Where *n* is the number of spatial units; S_0 the sum of the elements of the spatial weights matrix; *w* is a spatial weights matrix with $(n \times n)$ elements; and, finally, *x* is an observation vector $(n \times 1)$ of x_i of deviations from the mean $\bar{x}$. It is also possible to obtain Moran's I for two variables (bivariate). In this case, one seeks to know whether the value of a variable in a region is spatially related with the value of the other variable in neighboring regions. The equation in two variables is as follows:

$$\mathrm{I}^{xy} = \frac{n}{S_0}\left(\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i-\bar{x})(y_i-\bar{y})}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right) \qquad (2)$$

The symbols are the same as those already presented in equation 1, except in this case, the variable y_i and its mean $\bar{y}$ are introduced to represent the second variable of interest.

Moran's I reveals three types of information: the level of statistical significance allows us to conclude whether the data are randomly distributed or not; the statistically significant positive or negative sign reveals whether the data are concentrated or dispersed, respectively; and finally, the closer the value is to one, the stronger the spatial autocorrelation (concentration), whereas the closer to negative one, the stronger the dispersion. This information is shown in Moran's diagram of dispersion[8], which is divided into four quadrants, corresponding to the respective patterns of spatial association: High-High, Low-High, Low-Low and High-Low. Spatial autocorrelation of types High-High and Low-Low form clusters of similar values and reveal spatial heterogeneity (Almeida, Perobelli and Ferreira, 2008). The expected value of Moran's I $[\mathrm{E(I)} = \frac{-1}{(\mathrm{n}-1)}]$ represents what would be obtained if the data were randomly distributed, indicating a positive autocorrelation for observed values greater than expected and a negative one for values lower than expected. Since the test is dependent on the number of permutations, the *p-value* is a pseudo *p-value*.

For local analyses, the Local Indicators of Spatial Association (LISA) should be used (also known as Local Moran's I). This measures the individual contribution of each territory in the I statistic of Global Moran's. According to Miller (2004), this disaggregated spatial indicator captures spatial associations and heterogeneities simultaneously. The LISA statistic is calculated for the i^{th} location as follows:

$$I_i = Z_i \sum_{j=1}^{n} W_{ij} Z_j \tag{3}$$

in which Z_i and Z_j indicate the number of the variable analyzed by region i and j. W_{ij} indicate the elements of the spatial weights matrix W between points i and j; the sum is proportional to Global Moran's indicator, and can be interpreted as an indicator of local spatial agglomeration (Anselin, 1995). The weights matrix is exogenously determined and can be defined using contiguity, distance or more complex specifications. According to Le Sage (1999), the contiguity matrices can be: linear, tower, bishop, double linear, double tower and queen. Since this study analyzes the contiguous regions of mainland Portugal, which contain small regions, the Queen weights matrix of order one was used, which considers the regions that share sides and vertices in common in relation to the region of interest[9]. The LISA cluster map indicates significant local spatial correlations, interpreted in the same way as in the global Moran dispersion, across the four quadrants.

[8] An illustration of the diagram of dispersion of Moran's I can be seen in Figure B1 of Appendix B in the online supplementary data.

[9] A weights matrix was also tested, considering the inverse distance (number of neighbours and in kilometres), and the results remained stable and similar to those of continuity (Table A7 of Appendix A in the supplementary data), which ensures robustness to the chosen weights matrix (Le Sage and Pace, 2014).

4. Results

4.1 Exports and R&D expenditures: spatial autocorrelation and cluster formation

For the analyses of spatial autocorrelation[10], the facts relative to exports were organized by groups of technological intensity and total[11]. Values of Moran's I (univariate) of total exports are positive and relatively constant, from 2011 to 2018, and larger than expected (-0.045)[12], according to Table 1.

Table 1. Global Moran's I Univariate[(1)] Values of exports from Portugal, by groups of technological intensity annually from 2011-2018.

	Technological intensities[(2)]						
Year	HM	MHM	MM	MLM	MLNM	LNM	TOTAL
2011	0.186*	0.128	0.263**	0.309***	-0.162	0.152*	0.222**
2012	0.298***	0.152*	0.261**	0.334***	-0.157	0.168*	0.250**
2013	0.285***	0.136	0.268**	0.321***	-0.181	0.164*	0.243**
2014	0.273***	0.133	0.249**	0.317***	-0.06	0.133	0.239**
2015	0.314***	0.122	0.258**	0.266**	-0.137	0.181*	0.178*
2016	0.244**	0.120	0.261**	0.277**	-0.156	0.134	0.181*
2017	0.242**	0.144*	0.298***	0.320***	-0.186	0.212**	0.206**
2018	0.205**	0.137*	0.282**	0.289***	-0.165	0.184**	0.185**
2011-18	0.278**	0.136*	0.273**	0.301***	-0.166	0.171*	0.211**

[1]Empirical pseudo-significance based on 999 random permutations. ***, ** and * Statistical significance at the 0.01, 0.05 and 0.10 levels respectively.
[2]HM: High technological intensity of Manufacturing; MHM: Medium-High technological intensity of Manufacturing; MM: Medium technological intensity of Manufacturing; MLM: Medium-Low technological intensity of Manufacturing; MLNM: Medium-Low technological intensity of Non-Manufacturing; LNM: Low technological intensity of Non-Manufacturing; TOTAL: Represents the sum of technological intensities.

In detail, by groups of technological intensity, Medium-Low of Manufacturing had the biggest value for Global Moran's I (above 0.300), except in 2015, 2016 and 2018. On the other hand, only Medium-Low of Non-Manufacturing showed negative autocorrelation and was not statistically significant in all of the years analyzed. Thus, for this group Medium-Low of Non-Manufacturing, the hypothesis of absence of spatial autocorrelation among regions is not

[10] We used GeoDa software, available at: http://geodacenter.github.io/download.html (Accessed in September 2019).
[11] Data relative to descriptive statistics (mean, standard deviation, minimum, maximum and correlation matrix) and relative holdings can be found in tables A1 through A5 of Appendix A in the online supplementary data.
[12] The null hypothesis of the model is the absence of spatial autocorrelation.

statistically rejected. This group requires less knowledge 'shipped' in goods and services and, therefore, has fewer possibilities for interdependence and regional spillover (Audretsch and Feldman, 2004). It is also noteworthy that Medium-High of Manufacturing showed statistically non-significant values in five of the years analyzed and Low of Non-Manufacturing in two of them (Table 1).

The values for High of Manufacturing, Medium of Manufacturing and Medium-Low of Manufacturing were positive and statistically significant. For these intensities, spatial autocorrelation among regions was verified by their exports, confirming the importance of the OECD taxonomy, which treats manufacturing and non-manufacturing activities differently (Galindo-Rueda and Verger, 2016). In general, the existence of spatial autocorrelation of exports among the regions of Portugal was confirmed, with stable values over the years. These results corroborate those of Dall-Erba (2005), which showed the stability of spatial autocorrelation of exports from Portugal in a different period.

The pattern of spatial distribution of exports from Portugal, especially High-High and Low-Low, was found only for some regions and with varying intensities. The High-High Pattern, regardless of technological intensity, was found only in the *Área Metropolitana do Porto* (with 100% of occurrences during the period)[13] and for the *Região de Aveiro* (with 50% of occurrences during the period), according to Table 2. The *Área Metropolitana do Porto* showed positive, statistically significant value in all years, indicating that the region had similar and above-average values along with its neighbors, revealing a cluster[14]. It is worth noting that this region showed a High-High pattern in all of the years in the following intensities: High of Manufacturing; Medium of Manufacturing and Medium-Low of Manufacturing (Table 2).

In the *Região de Aveiro* the High-High pattern was also observed, albeit with lower percentages of yearly occurrences, in almost all the intensities, except for Medium of Manufacturing and Medium-Low of Non-Manufacturing. The *Oeste* also demonstrated the High-High pattern, although with only three occurrences. *Terras de Trás-os-Montes* showed a Low-Low pattern of spatial autocorrelation, in almost all technological intensities, except for the Medium-High of Manufacturing. It should be noted that the Low-Low pattern was also found for other regions (table 2). The High-Low pattern of spatial autocorrelation also showed clusters, although in much smaller numbers, only in *Terras de Trás-os-Montes*, and Low-High pattern in *Alentejo*

[13] Refers to the number of occurrences observed in each year of the 8-year period and the relative frequency of occurrences in the individual years.
[14] The annual results of Moran's I, by groups of technological intensity, can be seen in table A6 of Appendix A.

Litoral (Table 2). Essentially the analysis of the spatial autocorrelation patterns revealed spatial heterogeneity among the regions, in which clusters with the High-High pattern presented high dynamics while the Low-Low pattern presented reduced dynamics.

Table 2. Spatial Autocorrelation Pattern High-High, Low-Low, High-Low and Low-High, by groups of technological intensity(1) and percentage of occurrences, of exports from Portugal, in the period from 2011 to 2018.

	High–High		Low–Low	
Intensity(1)	**Region**	**%**	**Region**	**%**
HM	Área Metropolitana do Porto	100.0	Terras de Trás-os-Montes	87.5
	Região de Aveiro	75.0	Algarve	50.0
MHM	Oeste	100.0		
	Região de Aveiro	37.5		
MM	Área Metropolitana do Porto	100.0	Terras de Trás-os-Montes	50.0
MLM	Região de Aveiro	100.0	Terras de Trás-os-Montes	100.0
	Área Metropolitana do Porto	100.0	Baixo Alentejo	37.5
MLNM	Oeste	100.0	Alentejo Central	12.5
LNM	Oeste	100.0	Douro	50.0
	Região de Aveiro	25.0	Terras de Trás-os-Montes	12.5
			Alto Tâmega	12.5
			Ave	12.5
TOTAL	Área Metropolitana do Porto	100.0	Terras de Trás-os-Montes	100.0
	Região de Aveiro	50.0		
	High–Low		**Low–High**	
Intensity(1)	**Region**	**%**	**Region**	**%**
HM				
MHM	Terras de Trás-os-Montes	100.0		
MM				
MLM				
MLNM			Alentejo Litoral	100.0
LNM	Terras de Trás-os-Montes	12.5	Alentejo Central	37.5
TOTAL				

[1] See notes to Table 1.

With regards to the formation of spatial clusters, in the period from 2011 to 2018, as a result of the LISA methodological procedure, they were observed only for two regions: the *Área Metropolitana do Porto*[15] (High-High type) and *Terras de Trás-os-Montes*[16] (Low-Low pattern) (Figure 1). That is, the exports of these two regions showed similar, positive values to that of their neighbors, revealing spatial heterogeneity, with the clusters in the *Área Metropolitana do Porto* more dynamic (with above average values) compared to those in the

[15] Neighbouring regions are: *Região de Aveiro*; '*Viseu Dão Lafões*; *Tâmega e Sousa*; *Ave*; *Cávado*.
[16] Neighbouring regions are: *Alto Tâmega* and *Douro*.

Terras de Trás-os-Montes (with below average values)[17]. Martinho (2005), addressing the productivity of Portugal's economic sectors, identified spatial autocorrelation only for 'service sector productivity' and found spatial clusters for the *Área Metropolitana de Lisboa* (High-High) and for the *Alentejo Central* (Low-Low).

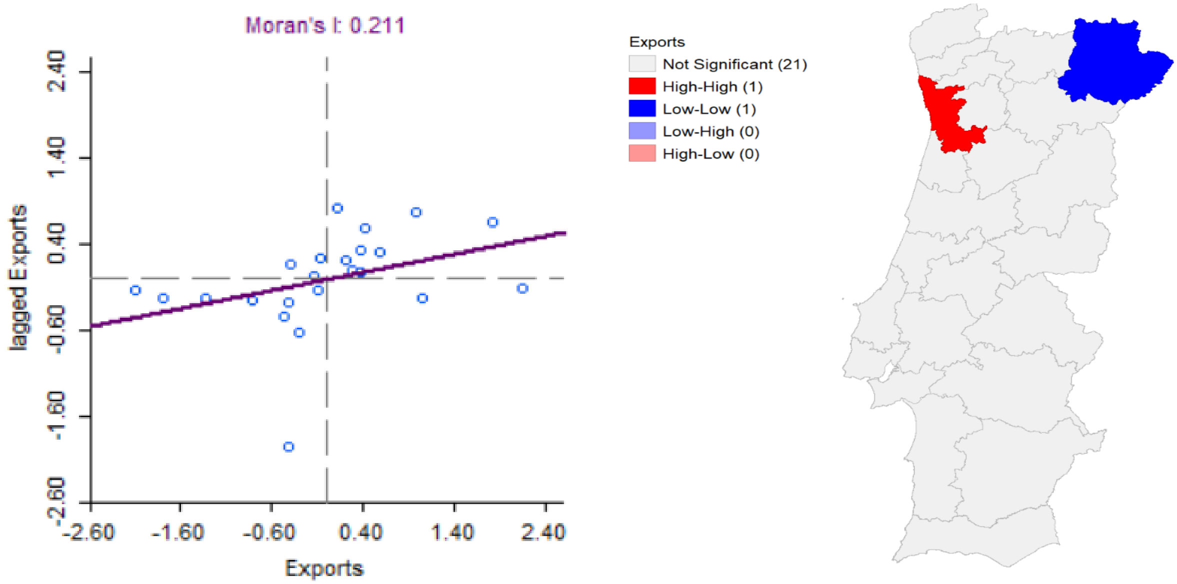

Figure 1. Dispersion diagram of Global Moran's Index and LISA cluster MAP of total exports from Portugal, 2011 to 2018.
Empirical pseudo-significance based on 999 random permutations. Significant Moran's I value at 0.05 level; Significant cluster map at 0.01 level (*Terras de Trás-os-Montes*) and at 0.05 level (*Área Metropolitana do Porto*).

The formation of spatial clusters may also be observed by groups of technological intensity. In this case, it is worth highlighting the group of High of Manufacturing[18], which presented clusters with High-High pattern for the *Área Metropolitana do Porto* and *Região de Aveiro*. For this same intensity, the Low-Low pattern was observed only in the *Terras de Trás-os-Montes*. For the High Manufacturing, Medium Manufacturing and Medium-Low Manufacturing intensities, Low-Low clusters were also observed for the *Terras de Trás-os-Montes*. For the Medium-Low of Non-Manufacturing groups, in all years analyzed, and for the group of Low of Non-Manufacturing, in 2016, 2017 and 2018, the Low-High pattern was observed in the *Alentejo Litoral*. Analyzing the first and last years of this study, there was little change: only the *Região de Aveiro*, in the High-High pattern, which formed clusters in three groups of

[17] Similar analyses may be deduced for the other technological intensities individually, using Figure B2 of Appendix B in the online supplemental data.
[18] This group is of great importance, since it consists of technology-intensive activities, with relatively higher levels of knowledge and more dynamic conditions for regional spillovers.

technological intensity, began to form into two groups in 2018. This reduction of clusters from three to two was also seen for the *Terra de Trás-os-Montes*, in the Low-Low pattern[19].

4.2 Autocorrelation and formation of spatial clusters: exports associated with R&D expenditures

Studies claim that exports of goods of greater technological intensity are associated with greater innovative efforts (Fagerberg, 1988; Dosi, Pavit and Soete, 1990; Audretsch and Feldman, 2004; Guarascio, Pianta and Bogliacino, 2016; López-Bazo and Motellón, 2018; Braja and Gemzik-Salwach, 2019). Following this theoretical and analytical perspective, an attempt was made to test for the existence of spatial autocorrelation between exports associated with R&D spending.

Table 3. Values of Global Moran's Bivariate I$^{(1)}$ for total exports and R&D expenditures for Portugal in the years 2011-2017.

	Technological intensities$^{(2)}$ and R&D						
Year	**HM and R&D**	**MHM and R&D**	**MM and R&D**	**MLM and R&D**	**MLNM and R&D**	**LNM and R&D**	**Total and R&D**
2011	0.117	0.194**	0.238**	0.210**	0017	0120	0.187**
2012	0190**	0173*	0.235**	0.224**	0.002	0.092	0.197**
2013	0.193**	0.199**	0.240**	0.233**	-0.006	0.075	0.202**
2014	0.162*	0.196**	0.245**	0.243**	0.047	0.054	0.200**
2015	0.193**	0.175*	0.245**	0.217**	0.000	0.092	0.184**
2016	0.176*	0.172*	0.262**	0.243**	0.006	0.092	0.195**
2017	0.172*	0.203**	0.294***	0.234**	0.001	0.091	0.193**
2011-17	0.178***	0.190**	0.256**	0.229**	0.008	0.080	0.196**

[1]Empirical pseudo-significance based on 999 random permutations. ***, ** and * Statistical significance at the 0.01, 0.05 and 0.10 levels respectively.
[2]See notes to Table 1.

With this analysis, the greatest values for Moran's I (bivariate) in all years were found in Medium of Manufacturing and R&D (0.256 from 2011-2017), indicating spatial concentration and spatial autocorrelation, according to Table 3. For High of Manufacturing and R&D the most technology-intense activities were found to be more concentrated and more associated with

[19] Annual analyses can be performed using tables A1 to A5 of Appendix A in the online supplementary data.

R&D expenditures, except for 2011. In this case, for the period as a whole, the results were positive and statistically significant, according to Table 3.

These results reveal, first, a direct relationship between exports and R&D, corroborating studies performed in various countries (Gomes and Faustino, 2011; Neves, Teixeira and Silva, 2016; Braja and Gemzik-Salwach, 2019) and, second, that this relationship was more intense in activities 'closer' to the High intensity technology group, such as Medium-High of Manufacturing and Medium of Manufacturing. On the other hand, the exceptions, which did not show spatial autocorrelation, were for Medium-Low of Non-Manufacturing and Low of Non-Manufacturing, according to Table 3. That is, spatial autocorrelation of exports and R&D among regions of Portugal was not found in non-manufacturing activities, confirming the importance of separately analyzing manufacturing and non-manufacturing activities.

Regarding the formation of spatial clusters, through LISA it was shown that of all the statistically significant technological intensities, the only region forming a spatial cluster, of the High-High type, was the *Região de Aveiro*, as shown in Figure 2 (cluster map). This means that the *Região de Aveiro* has high export values associated with high R&D spending figures from its neighboring regions[20].

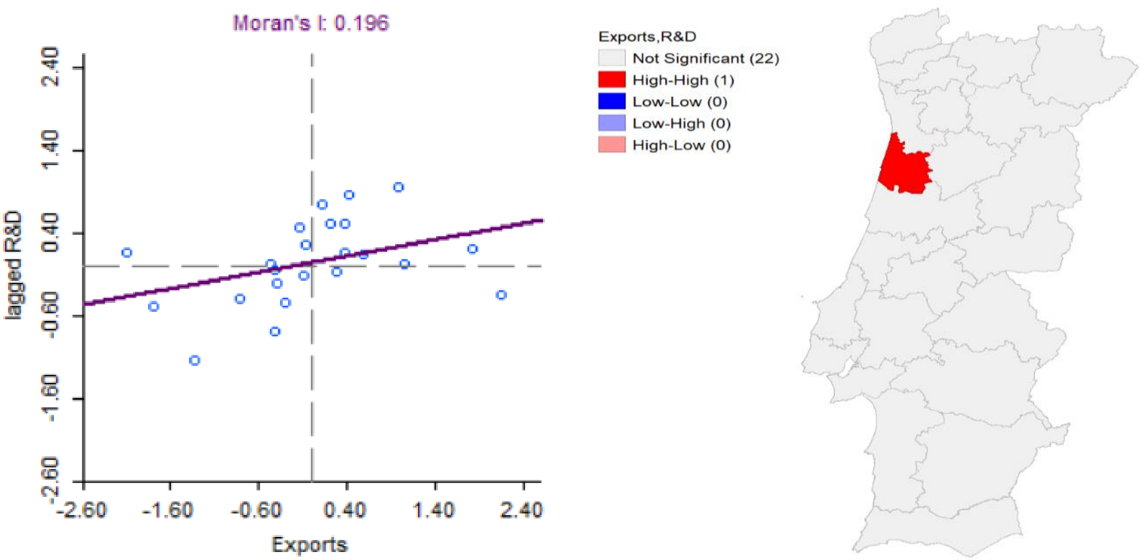

Figure 2. Dispersion diagram of bivariate Global Moran's I and LISA cluster Map of total exports and R&D expenses in Portugal, 2011 to 2017.
Empirical pseudo-significance based on 999 random permutations. Significant Moran's I value at 0.05 level; Significant cluster map at 0.01 level (*Região de Aveiro*).

[20] For the series of years analysed, the data can be consulted in Figure B3 of Appendix B in the online supplementary data.

5. Discussion

The analyzes confirmed the spatial autocorrelation of exports among regions of Portugal. In general, patterns of spatial distribution of the High-High type were verified for *Região de Aveiro* and *Área Metropolitana do Porto* and of the Low-Low type for *Terras de Trás-os-Montes*, with the formation of spatial clusters. The *Área Metropolitana de Lisboa* did not show formation of a spatial cluster for exports. Detailed analysis of this fact revealed, through Moran's dispersion diagram, that its neighboring regions were located in the Low-Low (*Alentejo Litoral*) and Low-High quadrants (*Lizíria do Tejo*, *Alentejo Central* and *Alentejo Litoral*) in practically all of the analyzed years. The exception was the *Oeste* which was always found in the High-High quadrant. In other words, for most of the neighboring regions there was no spillover of the positive externalities of the export dynamics of the *Área Metropolitana de Lisboa*, preventing the formation of clusters of the High-High pattern. In the case of *Área Metropolitana do Porto*, all of the neighboring regions, with the exception of 'Ave', were located in the High-High quadrant (*Área Metropolitana do Porto*, *Cávado*, *Alto Tâmega*, *Viseu Dão Lafões* and *Região de Aveiro*), contributing to the formation of the cluster.

The presence of positive autocorrelation in the *Área Metropolitana do Porto* was interesting to note. These results were quite robust, especially for groups of High of Manufacturing, Medium of Manufacturing, and Medium-Low of Manufacturing as well as for the total, showing spatial autocorrelation with spillover to neighboring regions (*Região de Aveiro*; *Viseu Dão Lafões*; *Tâmega e Sousa*; *Ave*; *Cávado*), which also showed similar values for their exports, confirming spatial interdependence and the formation of regional clusters. The *Região de Aveiro* and *Oeste* should also be highlighted. The former clearly integrated with the *Área Metropolitana do Porto*, revealing a certain 'symbiosis' with its neighbor, and is surrounded by regions with universities and research centers capable of promoting knowledge spillovers. This was similar, though less intense, in the *Oeste*, with positive autocorrelation in Medium-High of Manufacturing, Medium-Low of Non-Manufacturing and Low of Non-Manufacturing. These findings may be related to its proximity to the *Área Metropolitana de Lisboa*, where the results were revealing to a certain extent. Thus, this partially confirms the first hypothesis, since the formation of a spatial cluster was verified only for the *Área Metropolitana do Porto*, but not for *Área Metropolitana de Lisboa*.

The existence of spatial autocorrelation of R&D expenditures among the Portuguese regions was analyzed, and, since Moran's univariate I was not statistically significant, the null hypothesis of the absence of spatial autocorrelation was not rejected. A possible explanation would be that R&D spillovers are not sufficient among regions since knowledge can be predominantly tacit, similar to what was found in Guastella and van Oorte (2015). However, these results still do not appear convergent: Vaz et al. (2014), dividing Portugal into five regions, indicated a heterogeneity in the regional innovation profiles, showing divergence among their different patterns, with different spillover intensities. Faustino and Matos (2015), examining the determinants of exports in Portuguese firms, did not find statistically significant effects for R&D expenditures.

However, when looking at R&D associated with exports, the presence of spatial autocorrelation was observed only for manufacturing activities. Non-manufacturing activities, on the other hand, are distributed in a more random fashion with little (or no) relation to R&D expenses. The formation of spatial clusters found in this study corroborates this fact. Only one cluster of High-High type was observed, in the *Região de Aveiro*. In this case, *Região de Aveiro*'s export values were found to be above average and associated with above average R&D spending for neighboring regions, revealing positive spatial autocorrelation.

These results confirmed our second hypothesis, showing the existence of spatial autocorrelation between exports and R&D expenditures in Portugal and, at the same time, the presence of a spatial cluster in the *Região de Aveiro*. In this case, it is worth mentioning that the *Região de Aveiro* cluster regions have nationally and internationally recognized institutions of learning and research (Universities of Porto, Coimbra and Aveiro). A recent study by Silva, Silva and Carneiro (2017) assigned the best relative performance in the approval of R&D subsidy programs to the Universities of Coimbra and Aveiro. In the business sector, the University of Aveiro was also highlighted in a study on the importance of universities and research centers in the network of cooperation for projects of the Foundation for Science and Technology (FCT) (Gama, Barros and Fernandes, 2018). Similarly, Baptista and Mendonça, (2010) observed that the presence of universities in regions of Portugal had significant importance in the dynamics of sectors, especially those based on knowledge. Therefore, this set of assets related to innovation may stimulate the entry of firms, promoting economic activity in the region. From this same analytical perspective, Capello and Lenzi (2013) assert that this space can be characterized as a ‘functional domain’, with the potential to transmit knowledge to the cluster's productive sector, as seen in several studies (Capello and Lenzi, 2015, 2018 & 2019; Elvekrok et al., 2018).

6. Conclusions

This work analyzed the pattern of spatial distribution of exports from Portugal in the period from 2011 to 2018. From an empirical point of view, several interesting results were revealed. The first of these confirms previous studies for the Portuguese economy (Brito et al., 2015; Rebelo and Silva, 2017; Machado, 2019) with respect to the spatial concentration of economic activities in the large metropolitan areas, such as Lisbon and Porto, especially for the groups with the highest technological intensity.

The results of the spatial analysis of exports showed positive, statistically significant values of Moran's I in all the years and technological intensities, except for Medium-Low of Non-Manufacturing. This confirms that there is spatial autocorrelation of exports in the Portuguese regions, especially for groups with higher technological intensity, in the period examined. Also, the importance of separately analyzing manufacturing and non-manufacturing data was demonstrated, since only non-manufacturing exports are spatially dispersed and show no spatial interdependence. The existence of spatial autocorrelation of R&D expenditures was analyzed individually and no spatial dependence was found among the Portuguese regions. However, the results support the existence of spatial autocorrelation between exports and R&D spending among regions of Portugal that favor knowledge spillovers beyond their frontiers, forming spatial clusters in the *Região de Aveiro*.

It is worth noting that the comparison of research results is not always possible due to the specificity of the work and, consequently, the scarcity of empirical studies; on the other hand, while still recognizing that this study has some limitations, it opens up perspectives for future research. The first limitation is the nature of the data, aggregated at the regional and sector level by technological intensity, according to the new OECD taxonomy. Perhaps, using more detailed data at the regional or the sector level, we could obtain different results regarding the pattern of distribution of economic activities. It was not our objective to analyze and discuss the effects at the level of firms – their entry and exit – which can also change the pattern of localization of economic activities. For example, Beaudry and Schiffauerova (2009) conclude that different regional and also sectorial aggregations lead to different effects of agglomeration of economic activities on regional economic performance. Also Mameli, Faggian and Mccann (2014), Beaudry and Schiffauerova (2009) and Araújo, Gonçalves and Almeida (2019) argue that different levels of industrial breakdown lead to different empirical results for the same level of spatial aggregation.

Thus, it is necessary to further investigate the existence of a pattern of localization of economic activities as well as the agglomeration effects resulting from this pattern of localization on economic growth, using spatial panel econometrics. In this vein, Carreira and Lopes (2020) have already done work on the existence of externalities on employment and wages resulting from economies of specialization and diversification as well as regional knowledge, at the level of NUTS III regions of mainland Portugal, using spatial panel econometrics. It will therefore make sense to use these techniques in future work to analyze the externalities that could occur from the concentration of regional knowledge, through R&D investment on export activities and vice-versa, which could therefore contribute to regional and national economic growth. Besides this, as was already mentioned, the choice of the spacial weights matrix is relatively subjective and depends on the interest and object of each investigation. However, Corrado and Fingleton (2012) argue that the special weights matrix must be the result of economic and theoretical arguments that take into account the relations of input and output between the different sectors of economic activity and the fundamental regional infrastructures for the circulation of knowledge and innovation, which also stimulates future research. Finally, it may be useful to isolate the effects of the adjustment program in Portugal, which formally ended in 2014 and led to structural transformations in the Portuguese economy, which clearly adopted export-oriented economic growth policies, and to determine whether there was a change in the pattern of localization of export activities and also of knowledge-producing activities.

This research concludes at a moment of great uncertainty and expectations of an economic crisis, of unknown dimension, caused by the coronavirus (COVID-19) pandemic, which will require an effort from all civil society and the state. In this context, emergency and structural policies need to be delineated. The emergency ones are palliative, aimed at minimizing the harmful effects of the ‘state of emergency’ imposed by the state, which slowed economic activity, leaving their planning and execution to the current government, in the face of very short-term volatile scenarios. As for the structural policies (more long-term), this research provides us some clues, based on regional and intra-regional economic characteristics, which arise as a first step towards understanding their diverse realities and dynamics and, therefore, designing specific policies that take into consideration local specificities and potentialities (Massard and Autant-Bernard, 2015; Fratesi, 2015). In this sense, in line with Capello and Lenzi (2015), national policies should reinforce virtuous aspects and increase the efficiency of knowledge accumulation in each region.

Our results suggest not just incentivizing knowledge-generating activities, in their diverse forms, but, above all, actions that allow for understanding and enhancing the mechanisms of regional spillovers, especially by means of cooperation and productive complementarities (Capello and Lenzi, 2013; Guastella and van Oort, 2015; Gama, Barros and Fernandes, 2018; Capello and Lenzi, 2019). In addition, they recognize the importance of innovation in economic performance (and that businesses and regions are not alone in the innovative process) and the existence of spatial interrelations (Capello and Lenzi, 2013; Amoroso, Coad and Grassano, 2018). In this sense, national policies, with 'regional' foci, reinforcing partnerships through support networks, such as the triple or quadruple Helix, (Etzkowitz and Leydesdorff, 2000; Carayannis and Campbell, 2009), and greater interaction among universities, research centers and the productive sector, enhancing knowledge transfer to the firms (Camagni and Capello, 2013; Massard and Autant-Bernard, 2015; Capello and Lenzi 2018 & 2019), seem to be the most promising road to increase their effectiveness and promote better economic dynamics.

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APPENDIX A

Table A1. Descriptive statistics of total exports to Portugal, 2011 to 2018.

Technological intensities(1)	Mean	Std. Dev.	Min	Max
HM	19.0741	2.7152	14.5810	23.4574
MHM	20.6329	2.0353	15.8358	24.2546
MM	20.4413	1.8475	17.2741	23.4174
MLM	21.5477	1.6621	18.7452	24.7308
MLNM	17.4778	2.1999	12.0386	21.9447
LNM	19.7849	1.2052	17.7886	22.1248
TOTAL	22.6976	1.3063	19.9441	25.5120
R&D	12.0614	1.5833	9.6210	15.8634

[1]HM: High technological intensity of Manufacturing; MHM: Medium-High technological intensity of Manufacturing; MM: Medium technological intensity of Manufacturing; MLM: Medium-Low technological intensity of Manufacturing; MLNM: Medium-Low technological intensity of Non-Manufacturing; LNM: Low technological intensity of Non-Manufacturing; TOTAL: Represents the sum of technological intensities; R&D: Research and Development Expenses.

Table A2. Pearson's correlation matrix of data on total exports and R&D from Portugal, 2011 to 2018.

	HM	MHM	MM	MLM	MLNM	LNM	TOTAL	R&D
HM	1.0000							
MHM	0.5567	1.0000						
MM	0.6636	0.7774	1.0000					
MLM	0.7681	0.5800	0.7088	1.0000				
MLNM	0.5438	0.0066	0.2105	0.3883	1.0000			
LNM	0.3489	0.6135	0.5339	0.2911	0.2563	1.0000		
TOTAL	0.7719	0.7847	0.8012	0.8921	0.3405	0.5183	1.0000	
R&D	0.7869	0.5931	0.6121	0.6627	0.4544	0.5463	0.7082	1.0000

[1]See Notes to Table A1.

Table A3. Relative share of Portugal's exports (%), by NUTs and by groups of technological intensity[1], from 2011 to 2018.

NUTs[2]	HM	MHM	MM	MLM	MLNM	LNM	TOTAL
Terras de Trás-os-Montes	0.01	4.20	0.08	0.08	0.04	1.93	1.10
Douro	0.01	0.07	0.21	0.23	0.19	0.61	0.18
Tâmega e Sousa	0.98	0.36	1.14	6.20	0.61	0.30	3.14
Alto Tâmega	0.01	0.02	0.11	0.09	0.63	1.01	0.12
Área Metrop. do Porto	21.34	16.90	24.82	21.58	3.53	20.59	20.65
Algarve	0.17	0.17	0.10	0.13	0.59	3.99	0.33
Alentejo Central	5.56	0.35	0.80	0.57	1.07	1.12	1.13
Beiras e Serra da Estrela	2.55	0.50	0.53	1.13	2.64	0.41	1.04
Alto Alentejo	0.06	0.70	2.07	0.12	0.04	2.29	0.65
Lezíria do Tejo	0.20	1.52	1.16	2.12	3.88	4.20	1.75
Médio Tejo	0.08	2.03	2.66	1.70	1.24	0.68	1.70
Baixo Alentejo	0.12	0.01	0.09	0.62	53.63	1.49	1.27
Beira Baixa	0.03	0.18	0.05	2.28	0.02	0.46	1.09
Viseu Dão Lafões	2.32	3.14	1.28	2.58	0.50	3.51	2.48
Região de Leiria	0.35	3.76	8.37	1.34	2.68	4.72	3.08
Ave	2.11	1.61	13.19	10.98	0.40	1.44	7.61
Alentejo Litoral	0.01	2.76	2.90	0.53	0.00	5.24	1.57
Região de Coimbra	1.71	1.64	2.37	3.80	0.43	3.33	2.78
Região de Aveiro	8.51	9.37	13.80	3.35	0.66	4.87	6.95
Oeste	1.97	2.01	2.17	1.49	1.37	11.10	2.22
Área Metrop. de Lisboa	37.82	39.74	16.76	32.87	24.14	22.63	31.79
Cávado	10.93	2.18	3.04	4.19	0.25	0.57	4.04
Alto Minho	3.16	6.77	2.31	2.01	1.45	3.52	3.33
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[1] See Notes to Table A1.
[2]The description of the NUTs follows the order of construction of maps by the Shapefile file.

Table A4. Relative share of Portuguese exports (%), by groups of technological intensity[(1)] (2011 to 2018).

Ano	HM	MHM	MM	MLM	MLNM	LNM	TOTAL
2011	10.53	23.32	16.22	43.84	1.87	4.21	100.00
2012	10.85	22.75	16.59	43.65	1.90	4.27	100.00
2013	10.00	21.53	15.01	47.59	1.79	4.09	100.00
2014	10.03	21.50	15.21	46.93	1.76	4.57	100.00
2015	10.21	21.72	15.14	46.46	1.65	4.82	100.00
2016	12.07	21.83	16.04	43.55	1.41	5.10	100.00
2017	11.41	22.11	15.62	44.29	1.46	5.11	100.00
2018	10.83	26.97	16.42	38.62	1.67	5.50	100.00

[1] See Notes to Table A1.

Table A5. Relative share of R&D expenses in Portugal (%), by NUTs, from 2011 to 2018

NUTs(1)	2011	2012	2013	2014	2015	2016	2017	TOTAL
Terras de Trás-os-Montes	0.40	0.40	0.39	0.48	0.53	0.46	0.43	0.44
Douro	1.00	0.76	0.86	0.92	0.72	0.91	0.85	0.86
Tâmega e Sousa	0.19	0.17	0.18	0.17	0.18	0.21	0.19	0.19
Alto Tâmega	0.05	0.19	0.19	0.11	0.07	0.04	0.07	0.10
Área Metrop. do Porto	20.77	22.42	22.69	22.74	23.58	22.59	25.01	22.85
Algarve	1.19	1.31	1.18	1.33	1.32	1.27	1.07	1.23
Alentejo Central	0.94	1.25	1.14	1.09	1.15	1.27	1.30	1.16
Beiras e Serra da Estrela	0.90	0.87	1.03	1.15	1.05	1.20	1.17	1.06
Alto Alentejo	0.16	0.21	0.23	0.36	0.36	0.26	0.25	0.26
Lezíria do Tejo	0.45	0.49	0.59	0.59	0.66	0.76	0.77	0.62
Médio Tejo	0.30	0.37	0.44	0.46	0.38	0.42	0.48	0.41
Baixo Alentejo	0.28	0.22	0.23	0.26	0.49	0.37	0.41	0.33
Beira Baixa	0.21	0.21	0.43	0.33	0.27	0.38	0.37	0.32
Viseu Dão Lafões	0.66	0.64	0.54	0.70	0.60	0.69	0.71	0.65
Região de Leiria	1.30	1.61	1.35	1.36	1.21	1.31	1.29	1.34
Ave	2.22	2.09	2.00	2.09	2.45	2.53	2.45	2.27
Alentejo Litoral	0.08	0.10	0.06	0.07	0.09	0.13	0.10	0.09
Região de Coimbra	6.39	7.71	7.66	8.44	7.84	6.48	6.51	7.24
Região de Aveiro	5.35	5.53	5.43	5.63	5.22	6.01	5.95	5.60
Oeste	1.14	1.16	1.58	1.83	2.27	2.43	2.51	1.86
Área Metrop. de Lisboa	51.39	48.23	47.34	45.33	44.72	45.35	43.35	46.50
Cávado	4.06	3.54	3.87	4.05	4.43	4.35	4.05	4.06
Alto Minho	0.60	0.51	0.56	0.52	0.40	0.57	0.71	0.56
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[1]The description of the NUTs follows the order of construction of maps by the Shapefile.

Table A6. Spatial auto-correlation pattern of exports, by groups of technological intensity, to Portugal (NUTs III), for the years 2011 to 2018

Year	Intensity	High-High	Low-Low	High-Low	High-Low
2011	**HM**	Região de Aveiro; Área Met. do Porto	Algarve		
	MHM	Oeste; Região de Aveiro		Terras de Trás-os-Montes	
	MM	Área Met. do Porto	Terras de Trás-os-Montes		
	MLM	Área Met. do Porto; Região de Aveiro;	Terras de Trás-os-Montes		
	MLNM	Oeste			Alentejo Litoral
	LNM	Oeste	Terras de Trás-os-Montes; Douro; Alto Tâmega; Ave	Terras de Trás-os-Montes	
	TOTAL	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes;		
2012	**HM**	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes; Algarve		
	MHM	Oeste		Terras de Trás-os-Montes	
	MM	Área Met. do Porto	Terras de Trás-os-Montes;		
	MLM	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes		
	MLNM	Oeste			Alentejo Litoral
	LNM	Oeste	Douro		
	TOTAL	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes		
2013	**HM**	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes; Algarve		
	MHM	Oeste; Região de Aveiro		Terras de Trás-os-Montes	
	MM	Área Met. do Porto	Terras de Trás-os-Montes		
	MLM	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes		
	MLNM	Oeste			Alentejo Litoral
	LNM	Oeste;			
	TOTAL	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes		
2014	**HM**	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes		
	MHM	Oeste; Região de Aveiro		Terras de Trás-os-Montes	
	MM	Área Met. do Porto	Terras de Trás-os-Montes		
	MLM	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes		
	MLNM	Oeste			Alentejo Litoral
	LNM	Oeste; Região de Aveiro			
	TOTAL	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes		

Continuation

2015	**HM**	Área Met. do Porto	Terras de Trás-os-Montes		
	MHM	Oeste		Terras de Trás-os-Montes	
	MM	Área Met. do Porto			
	MLM	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes Baixo Alentejo		
	MLNM	Oeste			Alentejo Litoral
	LNM	Oeste; Região de Aveiro			
	TOTAL	Área Met. do Porto	Terras de Trás-os-Montes		
2016	**HM**	Área Met. do Porto	Terras de Trás-os-Montes		
	MHM	Oeste		Terras de Trás-os-Montes	
	MM	Área Met. do Porto			
	MLM	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes; Baixo Alentejo		
	MLNM	Oeste			Alentejo Litoral
	LNM	Oeste			Alentejo Central
	TOTAL	Área Met. do Porto	Terras de Trás-os-Montes		
2017	**HM**	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes		
	MHM	Oeste		Terras de Trás-os-Montes	
	MM	Área Met. do Porto			
	MLM	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes		
	MLNM	Oeste			Alentejo Litoral
	LNM	Oeste	Douro		Alentejo Central
	TOTAL	Área Met. do Porto	Terras de Trás-os-Montes		
2018	**HM**	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes; Algarve		
	MHM	Oeste		Terras de Trás-os-Montes	
	MM	Área Met. do Porto			
	MLM	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes; Baixo Alentejo		
	MLNM	Oeste	Alentejo Central		Alentejo Litoral
	LNM	Oeste	Douro		Alentejo Central
	TOTAL	Área Met. do Porto	Terras de Trás-os-Montes		

Continuation

2011-18	**HM**	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes;		
	MHM	Oeste		Terras de Trás-os-Montes	
	MM	Área Met. do Porto	Terras de Trás-os-Montes;		
	MLM	Região de Aveiro; Área Met. do Porto	Terras de Trás-os-Montes;		
	MLNM	Oeste			Alentejo Litoral
	LNM	Oeste	Douro		
	TOTAL	Área Met. do Porto	Terras de Trás-os-Montes		

[1] See Notes to Table A1.
[2]All clusters were significant at levels below 0.05 of significance.

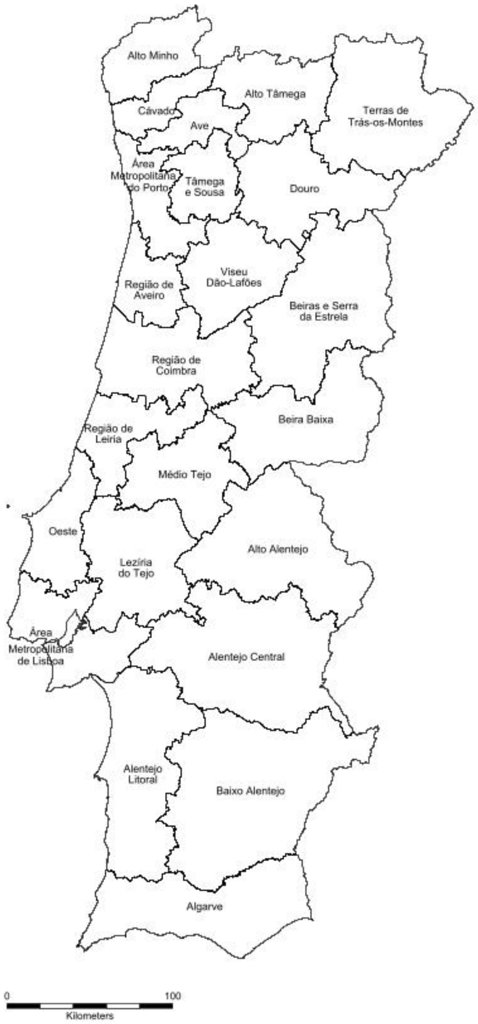
Table A7. Global Moran's I Univariate[(1)] Values of exports from Portugal, by groups of technological intensity, in the period from 2011 to2018, and by weight matrix.

	Technological Intensity[(2)]							
Matrix	**HM**	**MHM**	**MM**	**MLM**	**MLNM**	**LNM**	**TOTAL**	**R&D**
Queen	0.278**	0.136*	0.273**	0.301***	-0.166	0.171*	0.211**	0.004
Tower	0.278**	0.136*	0.273**	0.301***	-0.166	0.171*	0.211**	0.004
5 Neighbors	0,148***	0,074	0,188**	0,181**	-0,138	0,174**	0,168**	-0,034
7 Neighbors	0,031	-0,020	0,053	0,054	-0,091	0,056	0,006	-0,056
10 Neighbors	-0,057	-0,050	-0,005	-0,030	-0,090	0,015	-0,054	-0,049
Reverse Distance								
80 km	0,232**	0,134	0,370**	0,367***	-0,340**	0,275**	0,229**	0,132
90 km	0,235**	0,132***	0,293**	0,281**	-0,218***	0,180**	0,170**	0,110
100 km	0,097	0,073	0,230**	0,230**	-0,180**	0,170**	0,107	-0,037

[1]Empirical pseudo-significance based on 999 random permutations. ***, ** and * Statistical significance at the 0.01, 0.05 and 0.10 levels respectively.
[2] See Notes to Table A1.

APPENDIX B - MAPS, FIGURES AND GRAPHICS

Map B1. Map of Mainland Portugal (NUTs III)



Sourec: Own construction

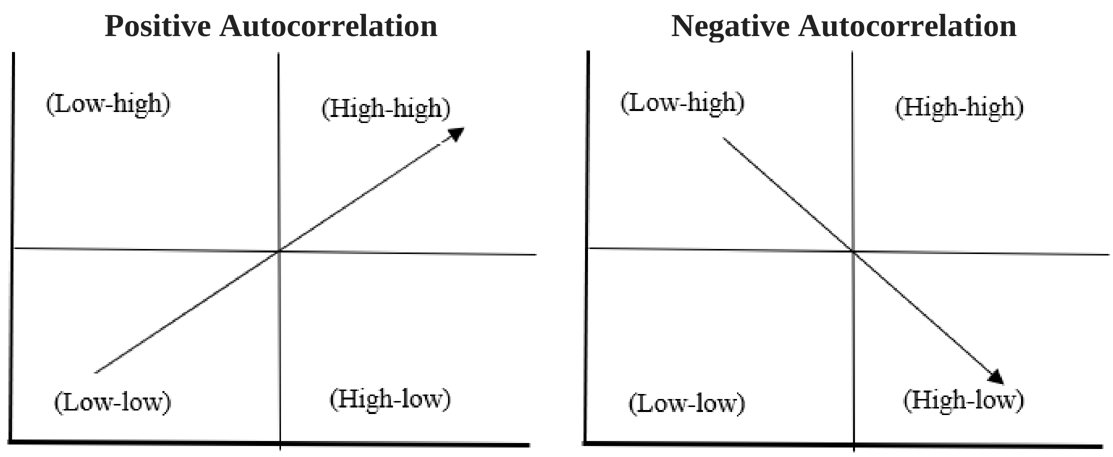
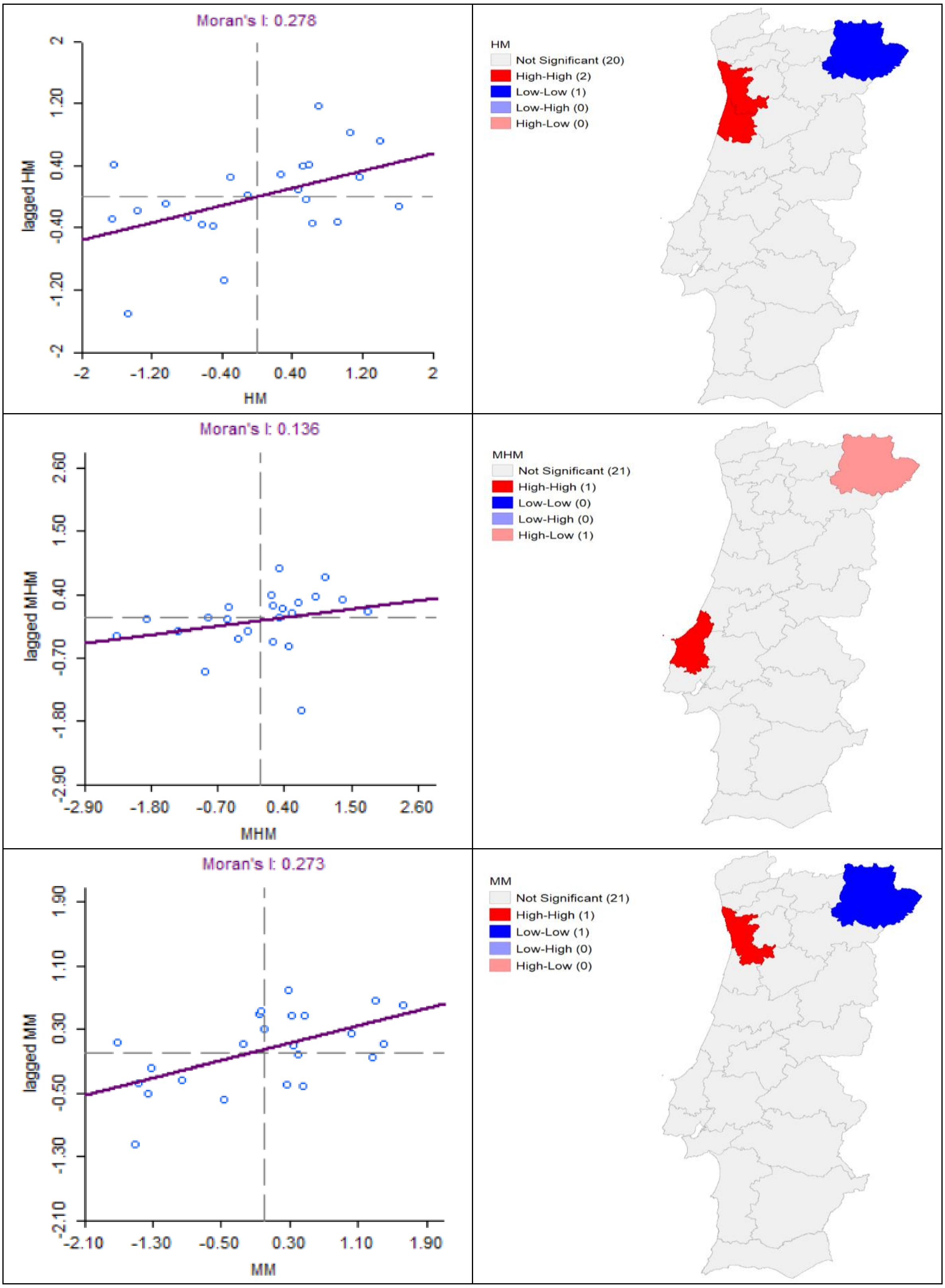


Figure B1. Moran dispersion diagram



Moran's I: 0.278
lagged HM
HM
-2
-1.20
-0.40
0.40
1.20
2
Not Significant (20)
High-High (2)
Low-Low (1)
Low-High (0)
High-Low (0)
Moran's I: 0.136
lagged MHM
MHM
-2.90
-1.80
-0.70
0.40
1.50
2.60
Not Significant (21)
High-High (1)
Low-Low (0)
Low-High (0)
High-Low (1)
Moran's I: 0.273
lagged MM
MM
-2.10
-1.30
-0.50
0.30
1.10
1.90
Not Significant (21)
High-High (1)
Low-Low (1)
Low-High (0)
High-Low (0)

Continuation

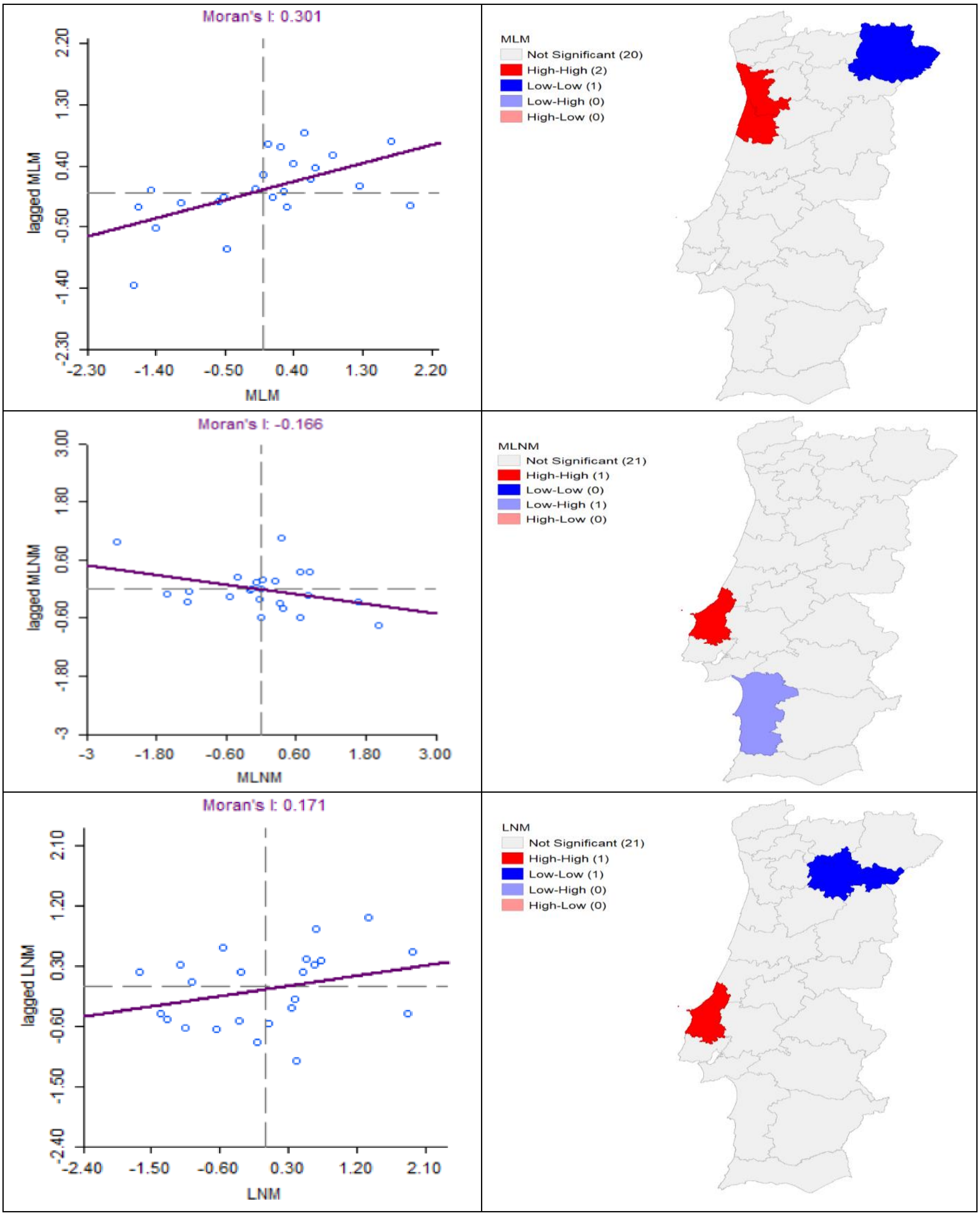
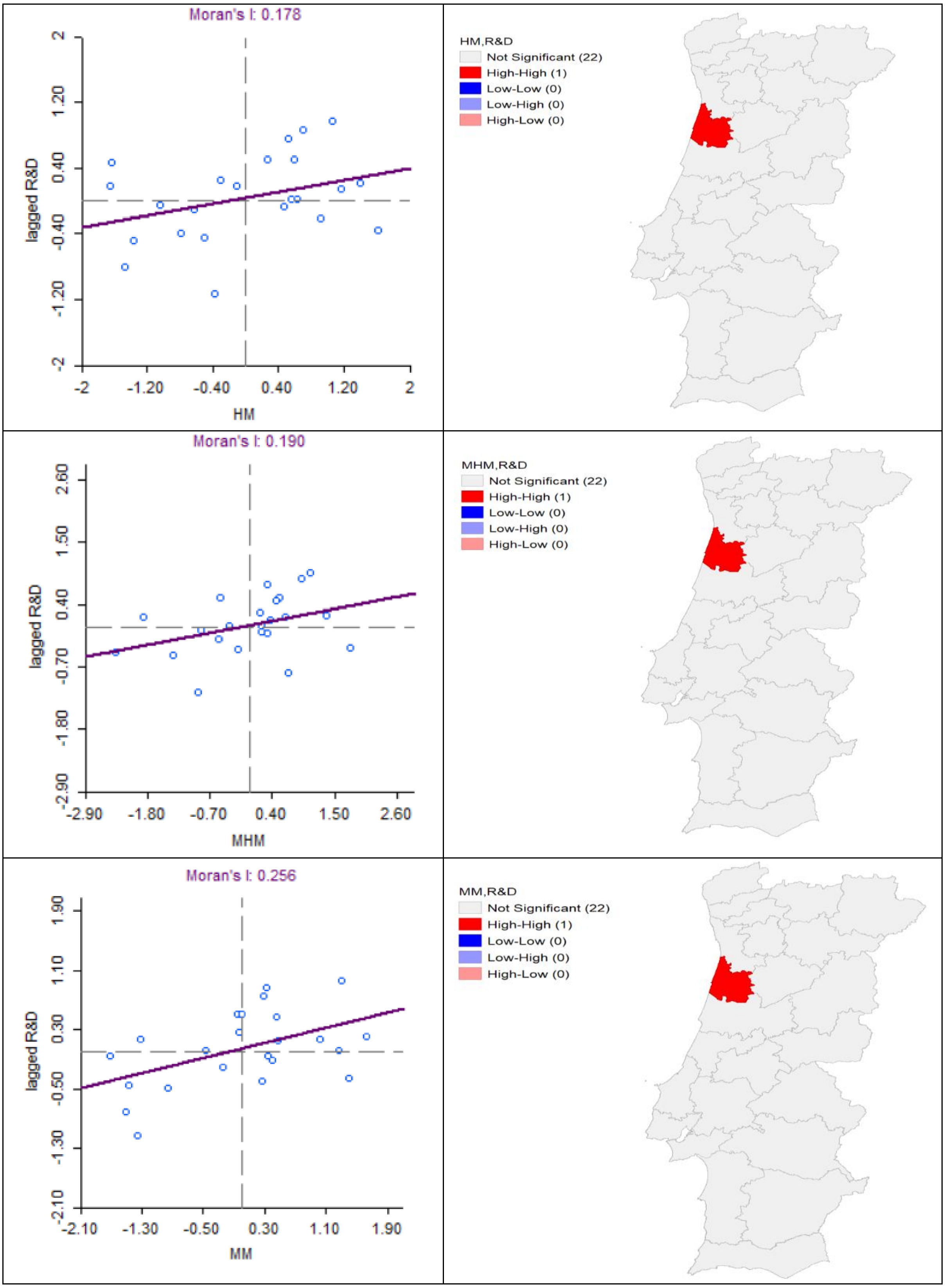


Figure B2. Dispersion diagram of the Moran Index and Map of LISA Clusters of Exports, by groups of technological intensity(1), Portugal, Period from 2011 to 2018.

[1] See Notes to Table A1.

[2]Empirical pseudo-significance based on 999 random permutations. Significant at the 0.01 significance level.


Moran's I: 0.178
lagged R&D
HM
HM,R&D
Not Significant (22)
High-High (1)
Low-Low (0)
Low-High (0)
High-Low (0)
Moran's I: 0.190
lagged R&D
MHM
MHM,R&D
Not Significant (22)
High-High (1)
Low-Low (0)
Low-High (0)
High-Low (0)
Moran's I: 0.256
lagged R&D
MM
MM,R&D
Not Significant (22)
High-High (1)
Low-Low (0)
Low-High (0)
High-Low (0)

Continuation

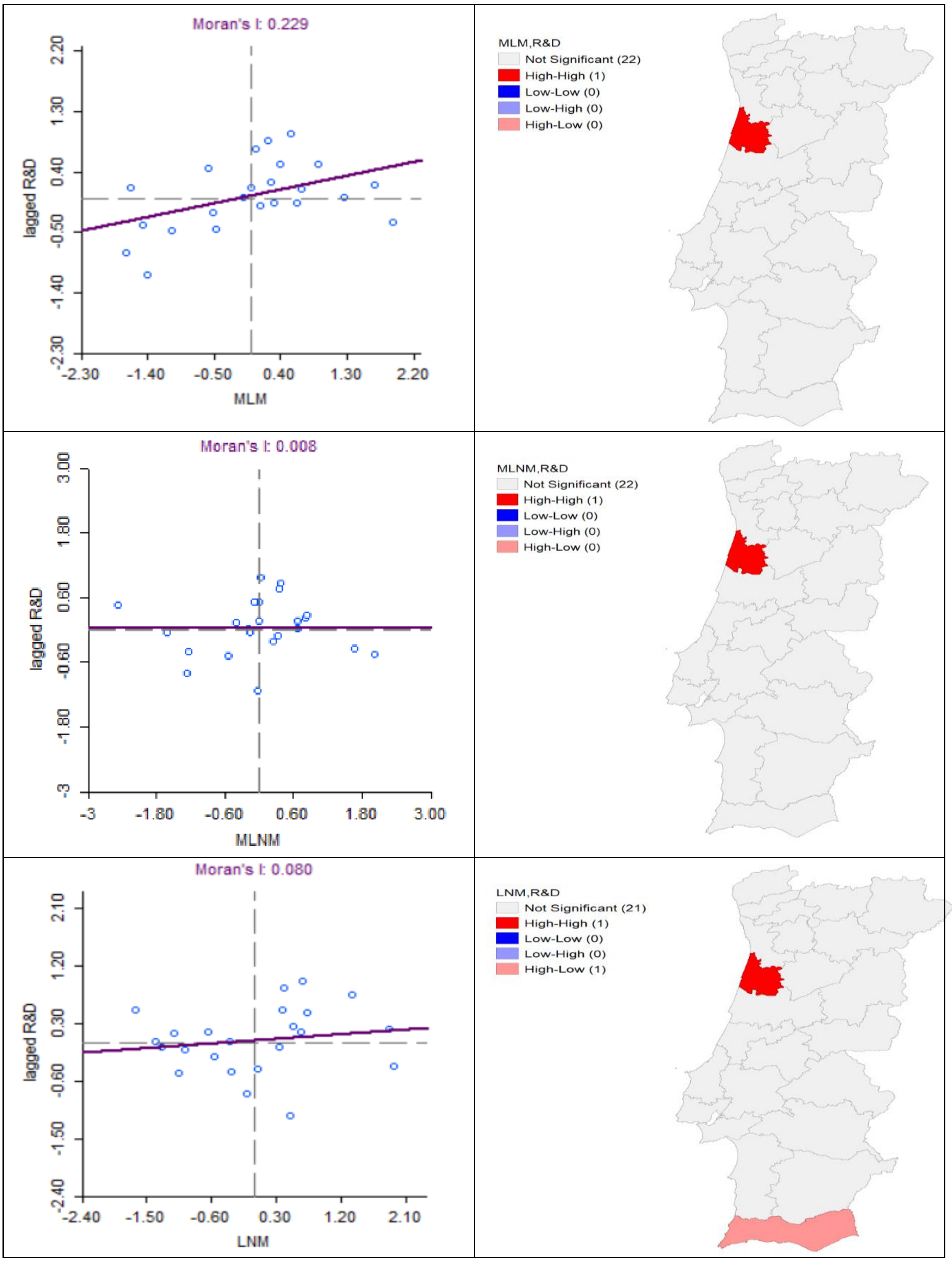


Figure B3. Dispersion diagram of the bivariate Moran Index and LISA Cluster Map of Exports, by groups of technological intensity(1), and of R&D expenses in Portugal, from 2011 to 2018.

[1]Empirical pseudo-significance based on 999 random permutations. Significant at a significance level of less than 0.05.

[2] See Notes to Table A1.

APPENDIX C

Methodological explanatory note:

The divisions 3, 4, 5, 7, 8 and 9 of the Combined Nomenclature (NC2) went entirely to Agriculture, livestock, forestry and fishing (divisions 1, 2 and 3 of the Economic Activities Classification - CAE Rev. 3).

Divisions 54 (Synthetic or artificial filaments; sheets and the like of synthetic or artificial materials) and 55 (Synthetic or artificial fibers, discontinuous) of NC2 went to division 13 of CAE Rev. 3 (Textile manufacture). This was done even though groups 5501 and 5504 of NC2 contained filaments and fibers pertaining to division 20 (Manufacture of chemicals and artificial or synthetic fibers, except pharmaceutical products), since these were a small fraction of this division. Division 54 of NC2 represents 4.48% of division 13 of CAE Rev. 3 and 6.65% of division 20 of CAE Rev. 3, while division 55 of NC2 represents 14.40% of division 13 of CAE Rev. 3 and 11.7% of division 20 of CAE Rev. 3. Therefore, all were classified in Division 13 of CAE Rev. 3.

Division 44 of NC2 (Wood, charcoal and wood works) was classified in division 16 of CAE Rev. 3 (Wood and cork industries and their works, except furniture; manufacture of basketry and wickerwork), since it deals with types of wood and derivatives with some degree of industrial transformation and, therefore is within Section C – "Industrial Transformation"; division 44 of NC2 represents 37.86% of division 16 in CAE Rev. 3.

Divisions 39 (Plastic and articles thereof) and 40 (Rubber and articles thereof) of NC2 appear in divisions 20 (Manufacture of chemicals and artificial or synthetic fibers, except pharmaceutical products) and 22 (Manufacture of rubber and plastic products) of CAE Rev. 3. Since the two correspond to 93.4% of division 22 of CAE Rev. 3. and 68.4% of division 20 of CAE Rev. 3, divisions 39 (Plastic) and 40 (Rubber) of NC2 went entirely to division 22 (Manufacture of rubber and plastic products).

Division 29 of NC2 (Organic chemicals) appears in divisions 20 (Manufacture of chemicals and artificial or synthetic fibers, except pharmaceutical products) and 21 (Manufacture of basic pharmaceutical products and pharmaceutical preparations) of CAE Rev. 3. Division 29 of NC2 represents 45.98% of division 21 and 12.29% of division 20 of CAE Rev. 3. Since division 21 of CAE Rev. 3 is very specific, Pharmaceutical products, and is equivalent to division 30 of NC2 (Pharmaceutical products), the decision was made to keep division 29 of NC2 in Division 20 of CAE Rev. 3 (Chemicals and chemical products).

Division 85 of NC2 (Machines, electrical equipment and materials and their parts; equipment for sound recording or reproduction, equipment for recording or reproduction of images and sound on television, and their parts and accessories) was classified in division 26 (Manufacture of computer equipment, communications equipment and electronic and optics equipment), since division 85 of NC2 was 77.2% of the total of division 26 of CAE Rev. 3.

Division 84 (Nuclear reactors, boilers, machines, mechanical appliances and instruments, and their parts) of NC2 strongly corresponds to both divisions 27 (Manufacture of electrical equipment) and 28 (Manufacture of machinery and equipment n.e.c.). Therefore, the decision was made to group the two divisions into one, without prejudice to future results, since both are classified as Medium-high technological intensity.

Division 87 of NC2 (Motor vehicles, tractors, cycles and other land vehicles, their parts and accessories) strongly corresponds to division 29 (Manufacture of motor vehicles, trailers, semi-trailers and motor vehicle parts) and groups 30.4 (Manufacture of military and combat vehicles) and 30.9 (Manufacture of transport equipment n.e.c.) of CAE Rev. 3. It was decided to classify division 87 of NC2 in Division 29 (Manufacture of motor vehicles, trailers, semi-trailers and motor vehicle parts) of CAE Rev. 3. It should be noted that division 29 and groups 30.4 and 30.9 of CAE Rev. 3, mentioned above, are classified as Medium-high technological intensity.

Division 37 of NC2 (Photography and cinematography products) was regrouped in divisions 59-60 of CAE Rev. 3 (Cinematographic, video, television program production, sound recording and music publishing activities + Radio and television activities). Division 27 of NC2 (Mineral fuels, mineral oils and their distillation products; bituminous materials; Mineral waxes) was maintained in division 19 of CAE Rev. 3 (Manufacture of coke, refined petroleum products and fuel agglomerates) of CAE Rev. 3, since division 27 constitutes practically all of division 19 of CAE Rev. 3.

In addition, it should be noted that division 20 (Manufacture of chemicals and artificial or synthetic fibers, except pharmaceutical products) of CAE Rev. 3 consists mainly of divisions 28 (Inorganic chemicals; inorganic or organic composites of precious metals, radioactive isotopes, rare earth metals or isotopes), 29 (Organic chemicals), and 31 (Fertilizers), among others from NC2.

For the Manufacturing Group: no correspondence was found between the Divisions of NC2 and Division 33 of CAE Rev. 3; therefore, division 33 of CAE Rev. 3 was not considered in this study. No correspondence was found between Divisions of NC2 and Group 18.2 of CAE; therefore, Group 18.2 of CAE was not considered in this study.

For the Non-Manufacturing Group: no correspondence was found among Divisions of NC2 for the following divisions of CAE Rev. 3: 72, 62, 63, 69 to 75X, 61, 64 to 66, 41 to 43, 77 to 82, 49 to 53, 55 to 56, and 68.

From the correspondence tables, the data were organized by year and by groups of activities by CAE Rev. 3, using the paper by Galindo-Rueda and Verger (2016), which presented work done for the OECD[21], proposing a new table of economic activities, by groups of technological intensity (High, Medium-High, Medium, Medium-Low and Low). The correspondence table for this study is shown in Table 01 in Appendix C.

[21] Galindo-Rueda, F.; Verger, F. OECD taxonomy of economic activities based on R&D intensity. *OECD Science, Technology and Industry. **Working Papers** No. 2016/04*. Paris: OECD Publishing, 2016.

APPENDIX D - TECHNOLOGICAL INTENSITY CLASSIFICATION TABLE

Table D1. Classification of technological intensities, with correspondences between the Combined Nomenclature (NC2) and Classification of Economic Activity CAE 3.1 Rev., by Division and groups for Portugal

Technological Intensity	Code NC2	Code (Division or Group) of CAE 3.1 Rev., and Activity Description
High		**Manufacturing**:
	88	Group 30.3 - Air and spacecraft and related machinery
	30	Division 21 – Pharmaceuticals;
	85	Division 26 - Computer, electronic and optical products
Medium-High		**Manufacturing**:
	93	Group 25.4: Weapons and ammunition;
	87	Division 29: Motor vehicles, trailers and semi-trailers;
	90	Group 32.5: Medical and dental instruments;
	84	Division 27: Electrical equipment; Division 28: Machinery and equipment n.e.c.
	28, 29, 31, 32, 33, 34, 35.	Division 20: Chemicals and chemical products;
	87	Group 30X: Railroad, military vehicles and transport n.e.c. (ISIC 302, 304 and 309);
Medium		**Manufacturing**:
	39, 40	Division 22: Rubber and plastic products;
	89	Group 30.1: Building of ships and boats;
	68, 69, 70	Division 23: Other non-metallic mineral products;
	72, 75, 76, 78, 79, 80, 81	Division 24: Basic metals;
Medium-Low		**Manufacturing**:
	50, 51, 52, 53, 54, 55, 57, 58, 59, 60, 63	Division 13: Textiles
	41, 42, 43, 64, 91	Division 15: Leather and related products
	47, 48, 56	Division 17: Paper and paper products
	2, 10, 11, 15, 16, 17, 18, 19, 20, 21, 23; 22, 24	Division 10-12: Food products, beverages and tobacco;
	61, 62, 65	Division 14: Wearing apparel
	73, 74, 82, 83	Group 25X: Fabricated metal products except weapons and ammunition (ISIC 25 less 252);
	27	Division 19: Coke and refined petroleum products;
	94	Division 31: Furniture;
	44, 45, 46	Division 16: Wood and products of wood and cork;
		Non-Manufacturing:
	25, 26	Division 05-09: Mining and quarrying;
	49	Group 58.1: Publishing of books and periodicals;
Low		**Non-Manufacturing**:
	38	Division 35-39: Electricity, gas and water supply, waste management and remediation;
	37	Division 59-60: Audio-visual and broadcasting activities
	1, 3, 4, 5, 6, 7, 8, 9, 12, 13, 14	Division 01-03: Agriculture, forestry and fishing
	97	Division 90-99: Arts, entertainment, repair of household goods and other services;

Source: INE (2019) - Meta Information System, available at: http://smi.ine.pt/.

Note: For some divisions and / or groups of CAE 3.1 Rev., it was not possible to establish a correspondence between CAE 3.1 Rev. and NC2 and, therefore, were not considered in the present study. They are: Division 72: Scientific research and development; Group 58.2: Systems development (software); Divisions 62-63: Other information services; Grupo 32Xs: Miscellaneous products, except code 32.5; Division 33: Maintenance, repair and installation of M & Es; Division 18: Printing and reproduction of recordings; Divisions 69-75X: Professional, scientific and technical activities, except R&D (ISIC 69-75 minus 72); Division 61: Telecommunications; Divisions 64-66: Financial, insurance and complementary; Divisions 45-47: Commerce; Divisions 41-43: Construction; Divisions 77-82: Administrative activities and complementary services; Divisions 49-53: Transport, storage and mail; Divisions 55-56: Accommodation and food; Division 68: Real estate activities.