The Drivers of National System of Innovation in Portugal: A Panel Data Analysis

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ABSTRACT

The growing awareness of the importance of national systems of innovation on countries’ development led to an increased availability of instruments designed to measure and compare the innovative capacity of countries. Such instruments provide policymakers with a panoply of relevant information, with which they can stimulate innovation within their territory, thereby increasing national competitiveness. Among the most used innovation indices, the Global Innovation Index (GII) stands out by explicitly distinguishing innovation inputs and outputs, hence, drawing from its input-output framework and extant literature on innovation, we intend to answer the question: Which innovation inputs are more strongly related to innovative outputs? Thus, deriving policy implications aimed at improving Portugal’s innovative readiness. To answer this question, and due to the cross-sectional nature of the GII, we have developed our own panel dataset version composed by 92 countries in the period 2013-2018, which we then analyse through a series of multiple regression techniques, emphasising the results of Eurozone countries and comparing Portugal to them. Results suggest a strong, positive influence of Business Sophistication on innovation outputs in Eurozone countries, derived mainly from the capacity of domestic firms to absorb knowledge. Possible policy implications are derived from this fact, such as, for instance, an encouragement to inward foreign direct investment. However, further research is needed to analyse the differentiated effects of such encouragement, as well as for other surprising results of our study.

Keywords: innovation, global innovation index, innovation inputs, innovation outputs, panel data, Portugal

INTRODUCTION

National Systems of Innovation (NSI) are recognised as cornerstones for countries’ development and international competitiveness (Fagerberg and Srholec, 2008; Freeman, 1987, 1995; Furman et al., 2002; Lundvall, 1992; Nelson, 1993), being recognised by the United Nations as part of one Sustainable Development Goal (SDG, UN, 2015). Edquist (2006: 182) defined NSI as

“all important economic, social, political, organisational, institutional, and other factors that influence the development, diffusion, and use of innovations”;

which highlights the essentially systemic nature of innovation, involving both organisations and state in the innovation process within a nation. In order to improve a country’s innovative capacities, policy decisionmakers must be able to understand which factors are driving innovation within their economies (Kuhlman et al., 2017). Following the you cannot manage what you cannot measure rationale, it becomes necessary to find ways of measuring the investment made in NSI and the resulting outcomes of such investments (Borrás and Laatsit, 2019). In fact, Archibugi et al. (2009) argues that there are at least three reasons that justify a systematic collection of innovation data. First, from a theoretical standpoint it allows academics to test innovation theories, since innovation has been considered a determinant of economic growth, employment, productivity, and competitiveness (Fagerberg and Srholec, 2008; Porter and Stern, 1999). Second, NSI measures allow policy decision makers to identify national strengths and weaknesses by comparison with other countries, as well as assessing the effectiveness of adopted policies. Third, they are extremely useful for business strategies, particularly as an aid to decision making regarding localisation of innovative activities along a company’s global value chain (Khan & Yu, 2019). To that end, several authors and major international organisations have developed frameworks to analyse the innovation readiness of countries, such as Porter and Stern (1999),

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Archibugi and Coco (2004), the European Innovation Scoreboard (European Comission, 2018), the OECD Science, Technology and Industry Scoreboard (STI, OECD, 2017), or the Global Innovation Index (GII, Cornell University et al., 2018).

These composite indicators are rather common in empirical research (Archibugi et al., 2009), having been used as tools to conduct case studies (Alfantookh and Bakry, 2015; Erciş and Ünal, 2016; Iqbal, 2011; Marx and Brunner, 2013), to rank countries according to their innovative capacity (Barragán-Ocaña et al., 2020; Edquist et al., 2018; Pençe et al., 2019), to assess ideal configurational conditions of NSI (Crespo and Crespo, 2016; Khedhaouria and Thuriš, 2017), or to analyse the relationships between the various NSI dimensions (Nasierowski and Arcelus, 1999; Sohn et al., 2016). However, although some empirical studies consider an input-output framework (Crespo and Crespo, 2016; Edquist et al., 2018; Khedhaouria and Thuriš, 2017; Nasierowski and Arcelus, 1999; Sohn et al., 2016), very few adopt a longitudinal perspective, considering at best a comparison between two consecutive years (Edquist et al., 2018; Zabala-Iturriagagoitia et al., 2007). The use of a cross-sectional perspective renders a static picture of the relationships between NSI dimensions in a given moment, thus failing to find evidence of the medium- to long-term impact of innovation inputs on innovative outputs. Therefore, to address this gap, we analyse the relationships between innovation inputs and outputs, while controlling for the effects of time. Drawing from the input-output framework (Godin, 2007), we intend to answer the question: Which innovation inputs are more strongly related to innovative outputs? Thus, deriving policy implications aimed at improving Portugal’s innovative readiness. To answer it, we rely on the framework provided by the GII due to its clear distinction between innovation inputs and outputs, based on more than 80 comparable indicators (Cornell University et al., 2018). The index, besides being developed by major international organisations, is audited by European Commission’s Joint Research Centre to attest its statistical validity. Therefore, it may be used as a leading reference for policymakers, business executives, as well as for researchers (Archibugi et al., 2009; Sohn et al., 2016). Nonetheless, the GII methodology gives rise to a number of difficulties if one aims to compare countries’ scores over time (Cornell University et al., 2018). The major concern in this respect is that reports are conducted to assess innovation readiness of countries in a given year, lacking a longitudinal framework to track changes over time. One of the GII’s aims is to include as many middle- and low-economies as possible, which, depending on the availability of data, results in different sample sizes throughout the years. To address this, and other methodological limitations of the GII, we have developed our own panel dataset version of the GII by following its methodology, to the extent possible, resulting in a set of 92 countries for six years (2013-2018). Our hypotheses are then tested by means of multiple regression analyses, in order to understand which inputs have a greater contribution to innovative outputs. Furthermore, we narrowed the analyses, focusing exclusively on a group of countries that, besides being subjected to similar innovation regulations and demands as Portugal, also share a deeper European integration in terms of currency, the Eurozone, which allowed us to make meaningful comparisons with Portugal.

The remainder of this paper is structured as follows. In section 2, we make a brief description of the GII, its components, methodology and limitations, followed, in section 3, with a development of our own panel dataset version of the GII. Next, in section 4, we elaborate on Portugal’s performance over time and compare it with the Eurozone average. In section 5, we propose a conceptual model to answer the research question and, following the literature review, we propose the hypothesis. The methodology used constitutes section 6. In section 7, results are presented and discussed, as well as the development of policy implications for Portugal. Lastly, section 8 concludes, including the study’s limitations and directions for future research.

THE GLOBAL INNOVATION INDEX (GII)

As mentioned before, we make use of the GII framework to analyse which innovation inputs are more strongly related to innovative outputs. The GII was launched in 2007 by INSEAD to shed light on the measurement of innovation readiness of countries and to find means of generating meaningful comparisons (Dutta et al., 2007), helping business leaders and public policymakers to understand the reasons of a nation’s relative performance (Dutta, 2009).

The latest GII report (Cornell University et al., 2018) covers 126 countries, compared along 80 indicators1. Its framework relies on the distinction between inputs and outputs to measure innovation in an economy, being inputs the elements of the national economy that enable innovative activities, and outputs the results of innovative activities within the economy. Indicators are aggregated in a total of 21 sub-pillars2, which, in turn, are aggregated under seven pillars. Five of those are input pillars, consisting in Institutions, Human Capital and Research, Infrastructure, Market Sophistication, and Business Sophistication, while two are output pillar, namely Knowledge and Technology Outputs, and Creative Outputs. Both input and output pillars are then aggregated to form the Input and the Output sub-indices (Figure 1).

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1 The number of countries included in each report varies from one year to the next, and the same happens to the indicators used.
2 Since 2013, only one sub-pillar had its name changed. Trade, competition, and market scale was called Trade and competition until 2015.
A weighted average of the normalised indicators forms the sub-pillars' scores, which, with another weighted average, form the pillars' scores. The input sub-index is obtained through a simple average of the five input pillars and output sub-index from a simple average of the two output pillars. The final GII results from the simple average of input and output sub-indices. The framework also includes an Innovation Efficiency Index, which is the ratio of the output sub-index over the input sub-index, showing how much innovation outputs a country is obtaining for its inputs.

The index relies on numerous sources of data, such as the World Intellectual Property Organization (WIPO), World Economic Forum’s (WEF) Executive Opinion Survey, World Bank’s Worldwide Governance Indicators and Doing Business, among many others. As such, the resulting data comes in three forms: hard data, composite indicators, and survey questions of WEF’s Executive Opinion Survey. In order to make meaningful comparisons, the indicators are subjected to a normalisation process using a min-max method.

Nevertheless, the use of GII scores as panel data is discouraged due to several methodological issues (Cornell University et al., 2018). First, the GII is compiled on an annual basis, providing a cross-country innovation performance assessment, hence presenting the characteristics of a cross-sectional study (i.e., several individuals at one moment in time) rather than panel data (several individuals tracked through several periods of time). As such, methodological changes from one year to the next distort the results in a panel study. Second, since 2007, the framework has undergone several changes in its structure, with the addition or removal of pillars, sub-pillars, and individual indicators. Third, from one year to the next, several countries are added or removed, based on the availability of indicators. Fourth, indicators’ collection over time suffer from changes in definitions and methodologies. Fifth, collected data undergoes a process of normalisation, thus rendering it incomparable in the presence of changes from one year to the next.

**PROPOSED PANEL DATASET VERSION OF THE GII**

To address the constraints expressed above, we took the following steps.

**Period Selection**

GII raw data is available in the website only since the 2013 report, hence we have considered the period from 2013 to 2018.

**Indicators Selection and Collection**

As mentioned above, some indicators were added or removed during the period of analysis. As such, aiming to maximise the total number of indicators, we have taken the following steps: (1) we dropped seven indicators which appeared only in 2013 and 2014 (Press freedom, Gross tertiary outbound enrolment, Electricity consumption, Market access for non-agricultural exports,
GMAT mean scores, GMAT test takers, and Daily newspapers circulation), and one whose only appearance is in 2018 (Mobile app creation); (2) we have also dropped two indicators for which we had only three consecutive years of data, due to lack of availability of data at the original source (Global R&D companies (average expenditure, top 3), and Patent families filed in at least two/three offices); (3) for two indicators, the last year was left blank due to a change in their collection methodology and lack of available data at the original source (High-tech and medium high-tech output, and Printing, publications and other media output). For the same reason, one indicator was left with the last two years blank (Wikipedia monthly edits) and one indicator was left with the first year blank (Entertainment and media market); (4) two other indicators were left with the last year blank due to their removal of the 2018 report (Ease of paying taxes, and Video uploads on YouTube). The complete list of indicators used, as well as their definitions, sources and time-series, is shown in Table A1 in Appendix.

Country Selection

Since the number of countries present in GII reports varies from one year to the next, we have first selected those which are present in every report in the period of 2013 to 2018. Next, following Cornell University et al. (2018), we dropped countries which had more than 33% of missing values of the 53 input indicators (average for the period), and more than 33% of missing values of the 27 output indicators (average for the period). As such, we have obtained a sample of 92 countries (Table A2 in Appendix) which, according to the World Bank’s World Development Indicators, in 2017 accounted for 69.5% of the world GDP (PPP $) and about 84.4% of the world’s population.

Identification and Treatment of Series with Outliers

Following the same methodology used in the GII, we have identified a total of 35 indicators with outliers that could polarise results: 34 out of the 57 hard data indicators and 1 out of the 18 composite indicators. The identification and treatment of series with outliers was done through the following steps: (1) first, we have used the criterion of absolute skewness greater than 2.25, or a kurtosis greater than 3.5 to identify problematic indicators; (2) then, series with one to five outliers (indicator 212) were winsorised, where the values distorting the indicator were assigned the next highest value, up to where the previous criterion was met (only one value was adjusted, from 64.997 to 64); (3) series with more than five outliers were multiplied by a given factor f (both positive and negative powers of 10 were used) and transformed into their natural logarithms according to the following formulas:

\[
\text{for ‘goods’ indicators: } \ln \frac{(\max \times f - 1)(\text{economy value} - \min)}{\max - \min} + 1
\]

\[
\text{for ‘bads’ indicators: } \ln \frac{(\max \times f - 1)(\max - \text{economy value})}{\max - \min} + 1
\]

Where ‘min’ and ‘max’ are the minimum and maximum indicator sample values, and ‘goods’ and ‘bads’ are indicators for which higher values indicates better and worse outcomes, respectively. For indicators 534 and 634, although the log transformation did lower their skewness and kurtosis values, it was not sufficient to meet the criterion (skewness 2.28 and kurtosis 34.33, and skewness 2.16 and kurtosis 43.21, respectively), hence we have decided to keep the transformed indicators avoiding further transformations.

Normalisation

According to the methodology of the GII, all 80 indicators were normalised into the [0,100] range, with higher score representing better outcomes. We used the min-max method to normalise indicators, where the min and max values were given by the minimum and maximum indicator sample value respectively, except for survey data and some indices, for which original ranges were kept as minimum and maximum values ([-2.5, 2.5] for the Worldwide Governance Indicators; [1, 7] for the World Economic Forum Executive Opinion Survey questions; [0, 100] for the QS World University Ranking; [0, 10] for the ITU indices; [0, 1] for the United Nations Public Administration Network indices; [1, 5] for the Logistics Performance Index; and [0, 100] for the Environmental Performance Index). Thus, we have applied the following formulas:

‘Goods’:

\[
\text{economy value} - \min \times \frac{100}{\max - \min}
\]

‘Bads’:

\[
\frac{\max - \text{economy value}}{\max - \min} \times 100
\]

Aggregation and Indices Construction

Normalised indicators were aggregated at the sub-pillar level via arithmetic average, which is rather common in the literature (Becker et al., 2018; Grupp and Schubert, 2010), with the weights proposed in Cornell University et al. (2018), namely 35 indicators were given a weight of 0.5 while the remaining 45 were given the weight of 1.0. These weights were used as scaling coefficients and not as importance coefficients, with the objective of obtaining indicators that can explain a similar amount of variance in their respective sub-pillar. Pillars were then created by a simple average of their respective sub-pillars, and the input and output sub-indices were created by a simple average of their respective pillars. Lastly, the overall index was created by a simple average of input and output sub-indices, while the efficiency index is the ratio of the output sub-index over the input sub-index.
Sophistication line to PORTUGAL developed, the first Switzerland and institutions.

Source: Ireland; Source: United Kingdom; HKG – Hong Kong (China); IRL – Ireland; KOR – Republic of Korea; LUX – Luxembourg; NLD – Netherlands; SGP – Singapore; SWE – Sweden; USA – United States of America.

Table 2. Mean scores and yearly means

| Variable                                | Mean       | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|-----------------------------------------|------------|------|------|------|------|------|------|
| Input sub-index                          | 35.08      | 34.04| 34.33| 34.93| 35.52| 36.29| 35.35|
| Output sub-index                         | 28.16      | 30.13| 28.86| 28.93| 27.82| 26.52| 26.68|
| GII                                     | 31.62      | 32.09| 31.60| 31.93| 31.67| 31.40| 31.01|
| Innovation Efficiency Index             | 0.802      | 0.895| 0.847| 0.827| 0.779| 0.721| 0.743|
| Input pillars:                           |            |      |      |      |      |      |      |
| Institutions                            | 50.62      | 49.24| 49.41| 51.05| 51.60| 51.47| 50.97|
| Human Capital and Research              | 25.41      | 25.50| 24.85| 25.82| 25.74| 25.83| 24.71|
| Infrastructure                          | 41.68      | 36.78| 38.11| 40.73| 43.39| 45.99| 45.09|
| Market Sophistication                   | 35.98      | 36.83| 37.33| 35.71| 35.08| 35.53| 35.38|
| Business Sophistication                 | 21.69      | 21.87| 21.95| 21.36| 21.77| 22.61| 20.58|
| Output pillars:                          |            |      |      |      |      |      |      |
| Knowledge and Technology Outputs         | 19.42      | 19.82| 19.49| 19.42| 19.72| 19.84| 18.23|
| Creative Outputs                        | 36.89      | 40.44| 38.23| 38.43| 35.91| 33.21| 35.13|

Source: Own calculations.

The resulting dataset is composed by 92 countries along six years (2013-2018). Table 1 ranks the top 10 countries on the GII and compares it against the newly developed panel data version framework (DuCa). One particularly interesting fact is that Switzerland lose its ubiquitous first place to Denmark, United States of America, and Netherlands, with Netherlands achieving the first position in three of the six years studied. Also, in the DuCa framework, Hong Kong, Singapore and Luxembourg never reach the top 10, whereas Republic of Korea does, first appearing in the 10th position in 2014 and maintains it from 2016 onwards.

Table 2 shows the mean values on the DuCa framework, both sub-indices, and the seven pillars, as well as their yearly means for the period 2013-2018. When looking at the output pillars, it can be seen that, on average, countries are far more productive in Creative Outputs than on Knowledge and Technology Outputs. Regarding inputs, Business Sophistication, followed by Human Capital and Research, are the less developed enablers of innovation, with Institutions and Infrastructure being the most developed, in average terms. Table 2 also reveals a negative trend of the overall index, with an increase in 2015. The Innovation Efficiency Index also decreases over time, although an improvement exists in the last year. This negative trend of innovation efficiency is due to both increases of inputs and decreases of outputs. Contrary to this overall negative trend, input pillars Institutions and Infrastructure revealed a positive evolution from 2013 to 2018.

From this point onwards, all analyses are based on the panel data version (DuCa) developed above. Nevertheless, the terms used will be those of the GII framework.

PORTUGAL’S PERFORMANCE

In this section, we describe Portugal’s innovation performance over time and relative to Eurozone. Table 3 shows Portugal’s overall ranking and scores down to the pillar level, revealing an overall ranking drop from the 29th position in 2013 to the 30th in 2018, notwithstanding climbs in 2014 (27th), 2015 (25th) and 2017 (28th). This shift in position is explained partially by Portugal’s performance and partially by other countries’ performance. For instance, we can observe a drop on Portugal’s GII score from 2013 to 2014, and yet it raised two positions on the ranking. Table 3 also reveals some trends over time, at the pillar level, which are in line with the overall trends for the total sample. Almost all pillars present a deterioration from 2013 to 2018, with the exception being Institutions (+10.5%) and Infrastructure (+21.8%). The largest negative variations from 2013 to 2018 are Market Sophistication (-16.0%), Human Capital and Research (-15.2%), and Business Sophistication (-12.7%).
Table 3. Portugal’s GII ranking and scores

| Variable             | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | Δ 13-18 |
|----------------------|-------|-------|-------|-------|-------|-------|--------|
| Input sub-index      | 39.83 | 40.76 | 42.13 | 41.23 | 41.61 | 39.63 | -0.5%  |
| Output sub-index     | 35.35 | 34.30 | 36.27 | 34.00 | 33.75 | 33.88 | -4.2%  |
| GII score            | 37.59 | 37.53 | 39.20 | 37.61 | 37.68 | 36.75 | -2.2%  |
| GII ranking          | 29    | 27    | 25    | 29    | 28    | 30    | -      |
| Innovation Efficiency Index | 0.887 | 0.842 | 0.861 | 0.825 | 0.811 | 0.855 | -3.6%  |

Input pillars:
- Institutions: 54.54
- Human Capital and Research: 37.25
- Infrastructure: 40.63
- Market Sophistication: 43.16
- Business Sophistication: 23.55

Output pillars:
- Knowledge and Technology Outputs: 21.53
- Creative Outputs: 49.17

Source: Own calculations.

Table 4. Eurozone countries GII scores

| Country            | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | Δ 13-18 |
|--------------------|-------|-------|-------|-------|-------|-------|--------|
| Austria            | 42.34 | 42.05 | 42.47 | 41.99 | 42.00 | 41.49 | -1.8%  |
| Belgium            | 39.38 | 38.84 | 39.10 | 39.26 | 39.14 | 38.49 | -2.3%  |
| Cyprus             | 38.39 | 33.92 | 33.71 | 35.70 | 35.60 | 34.59 | -9.9%  |
| Estonia            | 39.26 | 38.30 | 39.70 | 39.21 | 39.02 | 37.71 | -3.9%  |
| Finland            | 45.33 | 45.21 | 44.96 | 45.33 | 45.06 | 42.93 | -5.3%  |
| France             | 45.09 | 44.45 | 44.93 | 44.36 | 43.95 | 42.54 | -5.7%  |
| Germany            | 44.16 | 45.18 | 45.47 | 44.43 | 44.48 | 44.10 | 0.1%   |
| Greece             | 32.83 | 33.08 | 35.07 | 33.79 | 32.82 | 32.79 | -0.1%  |
| Ireland            | 45.35 | 45.32 | 45.63 | 43.86 | 42.62 | 41.69 | -8.1%  |
| Italy              | 37.62 | 36.97 | 38.45 | 37.78 | 37.29 | 36.94 | -1.8%  |
| Latvia             | -     | 35.00 | 36.39 | 36.92 | 36.71 | 34.57 | -1.2%  |
| Lithuania          | -     | -     | 34.57 | 34.35 | 33.90 | 33.28 | -3.7%  |
| Luxembourg         | 42.24 | 40.05 | 40.98 | 40.33 | 41.05 | 39.09 | -7.5%  |
| Malta              | 34.54 | 34.79 | 35.03 | 35.28 | 37.46 | 36.78 | 6.5%   |
| Netherlands        | 44.54 | 44.76 | 47.32 | 47.54 | 46.70 | 46.53 | 4.5%   |
| Portugal           | 37.59 | 37.53 | 39.20 | 37.61 | 37.68 | 36.75 | -2.2%  |
| Slovakia           | 33.31 | 32.82 | 34.04 | 33.34 | 33.25 | 32.50 | -2.4%  |
| Slovenia           | 39.03 | 38.17 | 38.63 | 37.87 | 37.89 | 37.57 | -3.7%  |
| Spain              | 40.06 | 39.94 | 40.47 | 39.15 | 38.86 | 38.23 | -4.6%  |
| Eurozone Mean      | 40.06 | 39.24 | 39.80 | 38.90 | 38.09 | 38.35 | -4.3%  |

Source: Own calculations.

Note: Latvia and Lithuania only joined the Eurozone in 2014 and 2015, respectively, hence the lack of values for such years. The variation for Latvia is from 2014 to 2018, and for Lithuania from 2015 to 2018.

Table 4 present the overall scores of Eurozone countries on the DuCa framework, highlighting Portugal’s scores and Eurozone mean. Overall, there is evidence of a decrease on the innovation index in the Eurozone, consistent with the tendency explored in the previous section (Table 2). However, some countries have evolved positively from 2013 to 2018, namely Malta (+6.5%) and Netherlands (+4.5%). As for Portugal, although a negative trend persists (-2.2%), its decline was less pronounced than that of the Eurozone mean (-4.3%).

Table 5 shows a comparison of Portugal’s scores against Eurozone’s and Eurozone Top 3 performers’ means, down to the pillar level, revealing that Portugal has space for improvement regarding its innovation convergence with its monetary partners. In a first analysis, comparing with Eurozone, in terms of innovation efficiency, Portugal is very close to Eurozone mean, having surpassed it in the last two years of the study. Table 5 also reveals a positive gap, towards Portugal, in the Human Capital and Research pillar, although the country has been losing ground since 2014. Market Sophistication in Portugal has been deteriorating, comparatively with Eurozone mean, where a positive gap existed in the early years of the study, it became a negative one in the latter years. Also worthy of highlight, Portugal’s largest gap towards Eurozone mean concerns Business Sophistication, which, in the last year, reached its peak (-23.8%), revealing an area worthy of improvement. Besides Business Sophistication, Portugal also presents moderately large gaps, towards the Eurozone, in Knowledge and Technology Outputs (-8.2% in 2018) and Infrastructure (-6.0% in 2018).

Comparing Portugal to Eurozone Top 3 performers, Table 5 reveals that, in 2018, the larger gap was in the Business Sophistication pillar (-38%), followed by Knowledge and Technology Outputs (-28%) and Human Capital and Research (-24%). Regarding the Human Capital and Research, even though Portugal stands above Eurozone mean, there is still a considerable gap towards the top performers, meaning there is plenty of space for improvement in this area.
Table 5. Portugal yearly scores versus Eurozone and Eurozone Top 3 means

| Variable                          | 2013   | 2014   | 2015   | 2016   | 2017   | 2018   |
|-----------------------------------|--------|--------|--------|--------|--------|--------|
| **Input sub-index**               |        |        |        |        |        |        |
| Portugal                          | 39.83  | 40.76  | 42.13  | 41.23  | 41.61  | 39.63  |
| Eurozone                          | 42.28  | 42.24  | 42.72  | 42.70  | 43.45  | 41.66  |
| Eurozone Top 3                    | 48.46  | 48.68  | 49.01  | 48.55  | 49.07  | 47.10  |
| Δ PRT vs Eurozone                 | -5.8%  | -3.5%  | -1.4%  | -3.4%  | -4.2%  | -4.9%  |
| Δ PRT vs Eurozone Top 3           | -17.8% | -16.3% | -14.0% | -15.1% | -15.2% | -15.9% |
| **Output sub-index**              |        |        |        |        |        |        |
| Portugal                          | 35.35  | 34.30  | 36.27  | 34.00  | 33.75  | 33.88  |
| Eurozone                          | 37.83  | 36.24  | 36.87  | 36.05  | 35.02  | 35.04  |
| Eurozone Top 3                    | 43.39  | 42.41  | 43.95  | 43.06  | 42.12  | 42.82  |
| Δ PRT vs Eurozone                 | -6.6%  | -5.4%  | -1.6%  | -5.7%  | -3.6%  | -3.3%  |
| Δ PRT vs Eurozone Top 3           | -18.5% | -19.1% | -17.5% | -21.0% | -19.9% | -20.9% |
| **GII**                           |        |        |        |        |        |        |
| Eurozone                          | 40.06  | 39.24  | 39.80  | 39.37  | 39.24  | 38.35  |
| Eurozone Top 3                    | 45.25  | 45.24  | 46.14  | 45.77  | 45.41  | 44.52  |
| Δ PRT vs Eurozone                 | -6.2%  | -4.4%  | -1.5%  | -4.5%  | -4.0%  | -4.2%  |
| Δ PRT vs Eurozone Top 3           | -16.9% | -17.0% | -15.0% | -17.8% | -17.0% | -17.5% |
| **Innovation Efficiency Index**   |        |        |        |        |        |        |
| Portugal                          | 0.887  | 0.842  | 0.861  | 0.825  | 0.811  | 0.855  |
| Eurozone                          | 0.897  | 0.859  | 0.862  | 0.844  | 0.805  | 0.840  |
| Eurozone Top 3                    | 0.953  | 0.918  | 0.936  | 0.950  | 0.917  | 0.964  |
| Δ PRT vs Eurozone                 | -1.1%  | -2.0%  | -0.1%  | -2.3%  | 0.7%   | 1.8%   |
| Δ PRT vs Eurozone Top 3           | -6.9%  | -8.3%  | -7.4%  | -13.2% | -11.6% | -11.3% |
| **Input pillars:**                |        |        |        |        |        |        |
| Institutions                      |        |        |        |        |        |        |
| Portugal                          | 54.54  | 57.32  | 60.66  | 60.44  | 61.42  | 60.24  |
| Eurozone                          | 59.82  | 59.44  | 60.14  | 60.71  | 60.72  | 59.74  |
| Eurozone Top 3                    | 70.00  | 69.58  | 68.73  | 69.00  | 67.70  | 66.94  |
| Δ PRT vs Eurozone                 | -8.8%  | -3.6%  | 0.9%   | -0.4%  | 1.2%   | 0.8%   |
| Δ PRT vs Eurozone Top 3           | -22.1% | -17.6% | -11.7% | -12.4% | -9.3%  | -10.0% |
| Human Capital and Research        |        |        |        |        |        |        |
| Portugal                          | 37.25  | 36.89  | 37.89  | 37.21  | 36.37  | 31.60  |
| Eurozone                          | 36.32  | 35.16  | 36.36  | 35.99  | 35.98  | 31.44  |
| Eurozone Top 3                    | 48.73  | 48.06  | 48.29  | 48.95  | 57.17  | 41.74  |
| Δ PRT vs Eurozone                 | 2.6%   | 4.9%   | 4.2%   | 3.4%   | 1.1%   | 0.5%   |
| Δ PRT vs Eurozone Top 3           | -23.6% | -23.2% | -21.5% | -24.0% | -36.4% | -24.3% |
| Infrastructure                    |        |        |        |        |        |        |
| Portugal                          | 40.63  | 42.65  | 45.35  | 47.94  | 50.00  | 49.48  |
| Eurozone                          | 43.71  | 44.95  | 48.15  | 50.42  | 53.19  | 52.64  |
| Eurozone Top 3                    | 50.90  | 52.64  | 54.54  | 56.59  | 57.63  | 58.82  |
| Δ PRT vs Eurozone                 | -7.0%  | -5.1%  | -5.8%  | -4.9%  | -6.0%  | -6.0%  |
| Δ PRT vs Eurozone Top 3           | -20.2% | -19.0% | -16.9% | -16.1% | -13.2% | -15.9% |
| Market Sophistication             |        |        |        |        |        |        |
| Portugal                          | 43.16  | 43.28  | 42.25  | 37.66  | 37.01  | 36.25  |
| Eurozone                          | 41.74  | 42.24  | 40.20  | 37.79  | 37.76  | 37.51  |
| Eurozone Top 3                    | 51.20  | 51.02  | 48.67  | 45.88  | 44.70  | 43.97  |
| Δ PRT vs Eurozone                 | 3.4%   | 2.5%   | 5.1%   | -0.3%  | -2.0%  | -3.4%  |
| Δ PRT vs Eurozone Top 3           | -15.7% | -15.2% | -13.2% | -17.9% | -17.2% | -17.6% |
| Business Sophistication           |        |        |        |        |        |        |
| Portugal                          | 23.55  | 23.64  | 24.47  | 22.87  | 23.24  | 20.56  |
| Eurozone                          | 29.81  | 29.43  | 28.77  | 28.58  | 29.58  | 26.97  |
| Eurozone Top 3                    | 37.97  | 36.16  | 36.34  | 35.36  | 36.50  | 33.15  |
| Δ PRT vs Eurozone                 | -21.0% | -19.7% | -14.9% | -20.0% | -21.4% | -23.8% |
| Δ PRT vs Eurozone Top 3           | -38.0% | -34.6% | -32.7% | -35.3% | -36.3% | -38.0% |

Source: Own calculations.

CONCEPTUAL MODEL, LITERATURE REVIEW AND HYPOTHESIS

Having perceived Portugal’s innovation position inside the Eurozone and possible areas for improvement, in this section we review the literature of national systems of innovation (NSI) and propose a conceptual model which intends to explain the
relationship between innovation inputs and outputs. Therefore, we intend to relate this section’s results to the previous contextual analyses, hence deriving policy implication for Portugal.

The national systems of innovations (NSI) perspective was introduced in the late 1980s (see Freeman, 1995; Lundvall, 1992; Nelson, 1993) and its diffusion among academic and policy circles has been surprisingly rapid (Teixeira, 2014). This approach, instead of focusing on specific aspects of innovation, takes on a more holistic perspective, emphasising the interactions between different actors and the influence of broader environmental factors, such as institutions (Edquist, 2006; Fagerberg et al., 2010). A consensual definitions of NSI is still non-existent. Freeman (1987: 1) considers it to be a “network of institutions in the public and private sector which activities and interactions initiate, modify, and diffuse new technologies”. Similarly, Nelson (1993: 4) defines them as “a set of institutions whose interactions determine the innovative performance (…) of national firms”. From a different perspective, Lundvall (1992: 13) sees them as “all parts and aspects of the economic structure and the institutional setup affecting learning as well as searching and exploring”. Although these definitions differ from one another, they encompass communalities, such as the focus on the relationships between institutions and organisations, and the interactions between them.

The measurement of NSI is a topic of ongoing debate (Gault, 2018; Grupp and Schubert, 2010; Nelson et al., 2014; Smith, 2006). In a seminal contribution to this issue, Smith (2006) revisited the traditional indicators used to measure innovation (R&D intensity and patents) as well as more recent approaches. In its conclusions, the author admitted that future developments could come from multi-indicator approaches. Indeed, several international organisations have developed efforts to measure NSI, such as the European Commission (Summary Innovation Index - SII), World Economic Forum (Global Competitiveness Report - GCR), Cornell University, INSEAD, and WIPO (Global Innovation Index - GII), the Organization for Economic Co-Operation and Development (OECD Science, Technology, and Industry Scoreboard - STI).

The main body of NSI research using composite indicators encompass four different types of research with distinctive methodologies associated. First, in-depth case studies use existing frameworks, such as the Global Competitiveness Report (GCR), the Summary Innovation Index (SII) or the GII to evaluate a country or region (Alfantookh and Bakry, 2015; Martin and Brunner, 2013), usually by comparison with other countries or regions. Second, drawing from existing frameworks, several studies develop alternative indices to rank the relative position of countries or regions (Barragán-Ocaña et al., 2020; Edquist et al., 2018; Zabala-Iturriaga and Ota et al., 2007). This studies typically consider an input-output framework since they adopt an efficiency perspective of NSI by means of data envelopment analysis methodologies. Third, to identify optimal configurational conditions of innovation, authors made use the innovation dimensions of the GII framework and apply a fuzzy-set qualitative comparative analysis (Crespo and Crespo, 2016; Khedhouri and Thirik, 2017). Lastly, studies aimed at identifying structural relationships between the various dimensions of innovation use the structural equations modelling methodology with both existing frameworks such as the GII (Sohn et al., 2016) and a collection of innovation indicators (Nasierowski and Arcelus, 1999). All of this research supports the notion that innovation inputs are transformed into innovative outputs. Also, Cornell University et al. (2018) describe a positive relationship between innovation inputs and outputs in every income groups, hence we propose the following hypothesis.

**H1: Innovation Inputs have a Positive Relationship with Innovation Outputs**

This pillar refers to the political environment (i.e. stability and effectiveness), the regulatory environment (i.e. rule of law and labour regulations), and business environment (i.e. ease of starting and ending a business). Institutions are understood as “humanly devised constraints that structure human interaction” (North, 1994: 360), which take the form of rules, laws, conventions or norms of behaviour. Lundvall (1992) recognised the institutional set up to be part of the national system of innovation, which, along with other factors, is capable of affect learning, searching, and exploring. Empirically, using patent grant data, Tebaldi and Elmslie (2013) found that institutional quality is positively related to patent counts across countries. On another study with a large sample of advanced and emerging economies, Silve and Plekhanov (2015) found that institutions are important determinants of innovation and, further still, that industries involving higher levels of innovation develop faster in countries with better economic institutions. Using GII data, Sohn et al. (2016) found a positive and indirect relationship between institutions and both knowledge and technological outputs and Creative Outputs. Previous research suggests that an institutional environment that provides good governance as well as protection and incentives is essential to innovation, hence we propose the following hypothesis.

**H2a: Institutions have a positive relationship with Knowledge and Technology Outputs.**

**H2b: Institutions have a positive relationship with Creative Outputs.**

Human capital and research pillar refer to countries’ education (i.e. government expenditure and student performance), tertiary education (i.e. enrolment, mobility, and graduates) and research (i.e. researchers and R&D intensity and activities). From the national systems of innovation perspective, education is one of the drivers of innovation (Freeman, 1995), encompassing university systems, available human capital resources, and the available knowledge stock (Åbel and Deitz, 2012; Bendapudi et al., 2018; Freeman, 1995). Van Hiel et al. (2018), using a large sample of countries with great variation in terms of Human Development Index (HDI), found that increasing levels of education, in high HDI countries, translates into better scores on national indices of innovation through the increase of liberalisation values in such societies. Also, Suseno et al. (2018) found that human capital, as well as social capital, have a significant effect on national innovation performance. Regarding the role of research on innovation, Bilbao-Osorio and Rodriguez-Pose (2004) conclude that private R&D activities are positively related to innovation in the European Union (EU). Sohn et al. (2016) found positive direct and indirect relationships between Human Capital and Research and both output pillars. Following the rationale where education can be considered an input to R&D activities, consequently resulting in increased innovation at the country level, we propose the following hypothesis.

**H3a: Human Capital and Research have a positive relationship with Knowledge and Technology Outputs.**

**H3b: Human Capital and Research have a positive relationship with Creative Outputs.**
Infrastructure pillar encompasses information and communication technologies (i.e. assess, use, and electronic government), general infrastructure (i.e. electricity, logistics, and physical infrastructures), and ecological sustainability (i.e. sound environmental practices). The infrastructural dimension assumes that good and ecological infrastructures facilitate the production and exchange of ideas, services and goods, which allows firms to increase their productivity, get better access to markets, and lower transaction costs (Arendt and Grabowski, 2017; Cornell University et al., 2018). For example, Cuevas-Vargas et al. (2016) found that the use of ICTs is a critical facilitator of innovation for micro, small, and medium sized enterprises in Mexico. Also, Martins and Veiga (2018) conclude that innovations in Portugal’s electronic government can lead to a more business-friendly environment, by reducing the administrative and regulatory burden. When analysing the drivers of EU’s circular economy, Cainelli et al. (2020) suggest that an environmental policy and green demand leads to an increase in eco-innovations by EU firms. Also, Sohn et al. (2016) discovered that Infrastructure has an indirect, positive, relationship with the two output pillars. Therefore, it is likely that well developed infrastructures positively affect innovation, hence we propose the following hypothesis.

**H4a: Infrastructure has a positive relationship with Knowledge and Technology Outputs.**

**H4b: Infrastructure has a positive relationship with Creative Outputs.**

Market sophistication pillar refers to domestic market quality, namely in terms of credit (i.e. ease of getting credit and its availability), investment (i.e. protection of minority investors and market value), and trade, competition, and market scale (i.e. tariff rates, competition, and GDP). Economic and finance literatures reveal a relationship between financial markets’ development and economic growth (Beck and Levine, 2002; King and Levine, 1993; La Porta et al., 1998). Fagerberg and Srholec (2008) stressed the importance of a country’s financial system in mobilising the necessary resources for innovation. Empirically, based on a three-decade panel of U.S. issued patents, Kortum and Lerner (2000) found that venture capital has a positive and significant impact on technological innovation. More recently, in a cross-country longitudinal study of the impact of financial market development on innovation, Hsu et al. (2014) found that industries more dependent on external financing and are high-tech intensive exhibit higher innovation levels in countries with better developed equity markets. When analysing debtor’s protection rights, Cerqueira et al. (2017) suggest that when debtor’s protection increases innovation decreases, due to a reduction in credit supply to small firms, particularly for those highly dependent on external financing. These findings are in line with those of Amore et al. (2013), who discovered that the availability and quality of credit by US banks had a positive impact on firms’ innovation. Also, Sohn et al. (2016) discovered a positive direct relationship between this pillar and both output pillars. As such, following the rationale that a country with sophisticated financial markets has better conditions for innovation to thrive, we propose the following hypothesis.

**H5a: Market Sophistication has a positive relationship with Knowledge and Technology Outputs.**

**H5b: Market Sophistication has a positive relationship with Creative Outputs.**

Business Sophistication pillar refers to knowledge workers (i.e. human capital employed by businesses), innovation linkages (i.e. linkages and partnerships between private, public and academic actors), and knowledge absorption (i.e. all high-tech and ICTs imports, intellectual property payments, FDI inflows, and researchers in business enterprises). For instance, Love and Mansury (2007), studying US business services, found that a highly qualified working force increases the probability of innovation. The authors also found that external linkages improve innovation performance. A study on Italian firms conducted by Maietta (2015) suggests that R&D collaboration between firms and universities have an impact on process innovation and a positive effect on product innovation for firms geographically closer to such entities. Also, Díez-Vial and Montoro-Sánchez (2016) found a positive relationship between the knowledge obtained by technology firms from universities and their levels of innovation. Regarding knowledge absorption, Liu and Zou (2008) found that R&D greenfield FDI significantly affects the innovation performance of domestic firms, finding evidence of both intra- and inter-industry spillovers. Also, Bertschek (1995) and Blind and Jungmittag (2004) found that both imports and inward FDI have positive and significant effects on product and process innovations. These results are in line with Khan and Yu (2019) suggestion that innovation is one the reasons why firms opt for global sourcing. Also, Sohn et al. (2016) discovered a positive direct relationship between the Business Sophistication pillar and the Creative Outputs pillar. Therefore, a country with higher business sophistication is likely to produce more innovative outputs, thus we propose the following hypothesis.

**H6a: Business Sophistication has a positive relationship with Knowledge and Technology Outputs.**

**H6b: Business Sophistication has a positive relationship with Creative Outputs.**

Figure 2 shows the proposed conceptual model, in which arrows represent the hypothesis developed above.
METHODOLOGY

Based on the DuCa framework put forth in section 3, we have developed a number of regression models in order to test the proposed hypothesis. We then applied the same models to a sub-sample composed exclusively of Eurozone members, in order to understand the behaviour of such relationships inside the European Monetary Union (EMU). All regressions were estimated using Gretl software (Cottrell and Lucchetti, 2009).

Data and Sample

As mentioned above, we have developed a panel dataset composed by 92 countries (see Table A2 in Appendix) during the period 2013 to 2018. Besides GI raw data, other sources were used, namely the International Labour Organization statistics (ILOSTAT), the UNESCO Institute for Statistics (UIS), the UN Comtrade database, the World Development Indicators from the World Bank, the World Intellectual Property Organization (WIPO) database, and the World Trade Organization (WTO) DATA.

Variables

Dependent variables. To analyse the relationship between innovation inputs and outputs, we used three dependent variables in separate models. First, the output sub-index (O4) is used to assess the effect of inputs on the overall score of innovation outputs. Then, we used the two output pillars (Knowledge and Technology Outputs (O5) and Creative Outputs (O7)) to further investigate the effects of innovation inputs in each outcome.

Independent variables. The explanatory variables used are the scores of the innovation input sub-index (I5) and the five input pillars, Institutions (I1), Human Capital and Research (I2), Infrastructure (I3), Market Sophistication (I4), and Business Sophistication (I5).

Model Specification

When conducting linear regressions with panel data, several estimators could be used, being the most common the pooled ordinary least squares (pOLS), the fixed effects estimator (FE), and the random effects estimator (RE) (Baltagi, 2015; Wooldridge, 2016). To choose an appropriate estimator, one must consider the nature and source of the data, as well as the methodology used to obtain it (for a discussion, see Hsiao, 2007). Apart from the theoretical discussion, Gretl provides a set of three statistical tests can be used to choose a particular estimator, namely an F test, in which the null hypothesis favours pOLS and the alternative the FE estimator, a Breusch-Pagan test, in which the null hypothesis favours pOLS and the alternative the RE estimator, and the Hausman test, in which the null hypothesis favours the RE estimator and the alternative the FE estimator.
In this sense, we developed four models in both pOLS and FE specification. The RE specification was not used, since the three tests indicated that a FE approach was appropriate. Therefore, to test hypothesis H1, we developed the following models:

\[ \text{I}_{it}^{\text{out}} = \beta_0 + \beta_1 \text{I}_{it}^{\text{in}} + \delta_1 d_{i1}^{14} + \delta_2 d_{i2}^{15} + \delta_3 d_{i3}^{16} + \delta_4 d_{i4}^{17} + \delta_5 d_{i5}^{18} + \alpha_i + \mu_{it} \]  \hspace{1cm} (1)

\[ \text{I}_{it}^{\text{out}} = \beta_0 + \beta_1 \text{I}_{it}^{\text{in}} + \delta_1 d_{i1}^{14} + \delta_2 d_{i2}^{15} + \delta_3 d_{i3}^{16} + \delta_4 d_{i4}^{17} + \delta_5 d_{i5}^{18} + \alpha_i + \mu_{it} \]  \hspace{1cm} (2)

Where, I\(_{it}\) is the dependent variable for each country (i) in each year (t), \(\beta_0\) is the intercept, \(\beta_i\) is the slope of the variable of interest, \(\delta_k\) (k=1,2,3,4,5) are the coefficients of year dummies included in the regression, \(\alpha_i\) is the individual fixed effect that does not vary over time, and \(\mu_{it}\) is the idiosyncratic error. We follow Wooldridge (2016) recommendation to include time dummies if T is small relative to N (in this case, \(T=6\) and \(N=92\)), to capture secular changes that are not being modelled. Eq. 1 refers to the pOLS specification. Eq. 2 to the FE specification, which does not include a constant.

The following models were developed to test hypothesis H2a, H3a, H4a, H5a, and H6a:

\[ \text{O}_{it}^{6} = \beta_0 + \beta_1 \text{I}_{it}^{11} + \beta_2 \text{I}_{it}^{12} + \beta_3 \text{I}_{it}^{13} + \beta_4 d_{i4}^{14} + \beta_5 d_{i5}^{15} + \delta_1 d_{i1}^{11} + \delta_2 d_{i2}^{12} + \delta_3 d_{i3}^{13} + \delta_4 d_{i4}^{14} + \delta_5 d_{i5}^{15} + \alpha_i + \mu_{it} \]  \hspace{1cm} (3)

\[ \text{O}_{it}^{6} = \beta_0 + \beta_1 \text{I}_{it}^{11} + \beta_2 \text{I}_{it}^{12} + \beta_3 \text{I}_{it}^{13} + \beta_4 d_{i4}^{14} + \beta_5 d_{i5}^{15} + \delta_1 d_{i1}^{11} + \delta_2 d_{i2}^{12} + \delta_3 d_{i3}^{13} + \delta_4 d_{i4}^{14} + \delta_5 d_{i5}^{15} + \alpha_i + \mu_{it} \]  \hspace{1cm} (4)

Where Eq. 3 refers to the pOLS specification and Eq. 4 to FE.

Lastly, to test hypothesis H2b, H3b, H4b, H5b, and H6b, we developed the following models:

\[ \text{O}_{it}^{7} = \beta_0 + \beta_1 \text{I}_{it}^{11} + \beta_2 \text{I}_{it}^{12} + \beta_3 \text{I}_{it}^{13} + \beta_4 d_{i4}^{14} + \beta_5 d_{i5}^{15} + \delta_1 d_{i1}^{11} + \delta_2 d_{i2}^{12} + \delta_3 d_{i3}^{13} + \delta_4 d_{i4}^{14} + \delta_5 d_{i5}^{15} + \alpha_i + \mu_{it} \]  \hspace{1cm} (5)

\[ \text{O}_{it}^{7} = \beta_0 + \beta_1 \text{I}_{it}^{11} + \beta_2 \text{I}_{it}^{12} + \beta_3 \text{I}_{it}^{13} + \beta_4 d_{i4}^{14} + \beta_5 d_{i5}^{15} + \delta_1 d_{i1}^{11} + \delta_2 d_{i2}^{12} + \delta_3 d_{i3}^{13} + \delta_4 d_{i4}^{14} + \delta_5 d_{i5}^{15} + \alpha_i + \mu_{it} \]  \hspace{1cm} (6)

Where Eq. 5 refers to pOLS specification and Eq. 6 to FE.

### RESULTS AND DISCUSSION

Table 6 shows the main descriptive statistics, the correlation matrix, and variance inflation factors (VIF). An analysis of the correlation matrix reveals the existence of significant correlations between the variables. Although a high correlation was expected between the input and output sub-indexes and their respective pillars, the existing correlations between the five input pillars could result in multicollinearity issues when regressed together. However, the highest VIF value (4.189 for variable I3) is below the common rule of thumb of 10 (Wooldridge, 2016), which indicates that multicollinearity should not be a problem.

Tables 7 and 8 display the results of the regressions used to test our hypothesis. Starting with the simple pooled OLS (pOLS), we can see that all panel tests indicate that a fixed effect (FE) approach is adequate. Together, the F, Breusch-Pagan, and Hausman tests reject the pOLS and random effects (RE) specifications, in favour of the FE approach. Also, the Welch F test rejects the null hypothesis that groups have a common intercept, thus rendering pOLS inadequate. Regarding the inclusion of time dummies, a Wald joint test rejects the null hypothesis of no time effects. Both pOLS and FE specifications are reported, however only the results from FE are discussed.

With the first model we intended to test if, in our sample, innovation inputs (Iin) are, in fact, transformed into innovation outputs (Iout) (Column 2, Table 7). Results reveal a surprising negative relationship between Innovation Inputs and Outputs sub-indices, although without statistical significance. This seems to contradict Cornell University et al. (2018), however, the authors obtained such evidence using an OLS estimator in a cross-sectional sample and our pOLS results (Column 1, Table 7) seem to corroborate this finding. Therefore, our results do not support Hypothesis H1.
Table 7. Results of regressions

| Dependent Variable | pOLS     | FE     |
|--------------------|----------|--------|
| Model              | (1)      | (2)    |
| Const.             | 1.814†   | -      |
| (1.060)            |          |
| lin                | 0.832*** | -0.089 |
| (0.031)            | (0.079)  |
| N                  | 552      | 552    |
| Adj. R²            |          | 0.8463 |
| Within R²          |          | 0.5327 |
| BIC                | 2.893.288| 2.395.491|
| Time dummies       | Yes      | Yes    |
| Wald F (5, 91)     | 77.141***| 53.201***|
| Panel tests:       |          |        |
| F (91, 454)        | 29.820***|
| Breusch-Pagan      | 754.472***|
| Hausman            | 185.983***|
| Welch F (91, 156.7)| 24.503***|

Source: Own calculation.

Note: †p ≤ 0.1; *p ≤ 0.05; **p ≤ 0.01; ***p ≤ 0.001. Below the coefficients are heteroskedasticity and autocorrelation (HAC) robust standard errors, in parenthesis. Out: Output sub-index; lin: Input sub-index; I1: Institutions; I2: Human capital and research; I3: Infrastructure; I4: Market sophistication; I5: Business sophistication; pOLS: Pooled OLS estimator; FE: Fixed effects estimator.

Table 8. Results of regressions (continuation)

| Dependent Variable | pOLS     | FE     | pOLS     | FE     |
|--------------------|----------|--------|----------|--------|
| Model              | (3)      | (4)    | (5)      | (6)    |
| Const.             | 5.473*** | -      | 4.813†   | -      |
| (1.304)            | (2.653)  |
| I1                 | -0.054   | -0.049 | 0.267*** | -0.122 |
| (0.047)            | (0.033)  | (0.051) | (0.083)  |
| I2                 | 0.213*** | 0.018  | 0.184*   | -0.088*|
| (0.038)            | (0.029)  | (0.075) | (0.044)  |
| I3                 | 0.075†   | 0.047  | 0.220**  | -0.081 |
| (0.045)            | (0.036)  | (0.082) | (0.064)  |
| I4                 | 0.032    | -0.020 | 0.011    | -0.107 |
| (0.042)            | (0.040)  | (0.072) | (0.080)  |
| I5                 | 0.348*** | 0.079† | 0.424*** | 0.099  |
| (0.057)            | (0.041)  | (0.089) | (0.067)  |
| N                  | 552      | 552    | 552      | 552    |
| Adj. R²            | 0.7885   | 0.8285 |
| Within R²          | 0.2847   | 0.5693 |
| BIC                | 2.763.213| 2.140.114| 3.325.905| 3.036.776|
| Time dummies       | Yes      | Yes    | Yes      | Yes    |
| Wald F (5, 91)     | 5.370*** | 21.492***| 48.484***| 37.984***|
| Panel tests:       |          |        |
| F (91, 450)        | 38.325***| 18.696***|
| Breusch-Pagan      | 836.190***| 570.579***|
| Hausman            | 116.239***| 159.923***|
| Welch F (91, 156.7)| 47.884***| 18.582***|

Source: Own calculation.

Note: †p ≤ 0.1; *p ≤ 0.05; **p ≤ 0.01; ***p ≤ 0.001. Below the coefficients are heteroskedasticity and autocorrelation (HAC) robust standard errors, in parenthesis. O6: Knowledge and technology outputs; O7: Creative outputs; I1: Institutions; I2: Human capital and research; I3: Infrastructure; I4: Market sophistication; I5: Business sophistication; pOLS: Pooled OLS estimator; FE: Fixed effects estimator.

Table 8 shows the results of regressing the five input pillars on both output pillars. When analysing the effects of input pillars on Knowledge and Technology Outputs (O6) (Column 4, Table 8), we found that only Business Sophistication has a significant effect (p = 0.0575) with a positive sign, thus supporting Hypothesis H6a. As such, results do not support Hypothesis H2a, H3a, H4a, and H5a. However, we also found negative effects, albeit not statistically significant, of Institutions (I1) and Market Sophistication (I4) on Knowledge and Technology Outputs (O6). On Column 6 (Table 8), only Human Capital and Research (I2) was found to have a statistically significant relationship with Creative Outputs (O7) (p = 0.0483) which, having a negative sign, rejects Hypothesis H3b. The remaining input pillars did not attain statistical significance, hence failing to support Hypothesis H2b, H4b, H5b, and H6b.

Of the two output pillars, results suggest that Business Sophistication relates more to the traditional measures of innovation (i.e., Knowledge and Technology Outputs) than to more creative forms of innovation (i.e., Creative Outputs), suggesting that the employment of knowledge workers, the quality of linkages between public organisations, universities, and private firms, and the
Table 9. Results of Fixed Effects regressions (Eurozone sub-sample)

| Dependent Variable | iout | O6  | O7  |
|--------------------|------|-----|-----|
| Model              | FE   | FE  | FE  |
| (7)                | (8)  | (9) |
| Iin                | 0.254| -   | -   |
| (0.226)            |      |     |     |
| I1                 | -    | 0.055| -0.093|
|                    |      | (0.142) | (0.115) |
| I2                 | -    | 0.007| -0.117|
|                    |      | (0.048) | (0.073) |
| I3                 | -    | 0.091| -0.095|
|                    |      | (0.114) | (0.089) |
| I4                 | -    | -0.025| 0.023|
|                    |      | (0.118) | (0.126) |
| I5                 | -    | 0.298†| 0.300*|
|                    |      | (0.153) | (0.132) |
| N                  | 111  | 111 | 111 |
| Within R²          | 0.3893 | 0.4183 | 0.6183 |
| BIC                | 447.751 | 466.980 | 516.625 |
| Time dummies       | Yes  | Yes | Yes |
| Wald F (5, 18)     | 14.896*** | 8.153*** | 18.993*** |

Source: Own calculation.
Note: † p ≤ 0.1; * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001. Below the coefficients are heteroskedasticity and autocorrelation (HAC) robust standard errors, in parenthesis. iout: Output sub-index; O6: Knowledge and technology outputs; O7: Creative outputs; Iin: Input sub-index; I1: Institutions; I2: Human capital and research; I3: Infrastructure; I4: Market sophistication; I5: Business sophistication; FE: Fixed effects estimator.

The economy’s knowledge absorption capacity are strong inducers of technological innovation. Similar conclusions can be found in several studies (Bertschek, 1995; Blind and Jungmittag, 2004; Díez-Vial and Montoro-Sánchez, 2016; Liu and Zou, 2008; Love and Mansury, 2007; Maitia, 2015). The negative relationship observed between Human Capital and Research and Creative Outputs could probably be one of methodological concern. One could argue that investments in education and research are not instantaneously transformed into innovation outputs. To this end, we have introduced time lags, up to two years, in this variable. In both cases, it loses its statistical significance but remains with a negative sign. It is likely that longer time-series are needed to properly assess this relationship. It is also likely that mediating and/or moderating effects could be present, as noted by Sohn et al. (2016), thus explaining the negative direct relationship. Also, by pooling a large number of countries with very different levels of development of education, research and innovation, the negative influences could outweigh the positive ones in our sample.

Eurozone Analyses

In order to approximate our estimations to Portugal, in this section we conduct similar analyses with a Eurozone sub-sample. Therefore, results could serve as references to derive policy implication for Portugal. Table 9 presents the results of FE regressions conducted in the Eurozone sub-sample, which is composed by the 19 countries using the Euro during the period 2013-2018, excluding Latvia in 2013 and Lithuania in 2013 and 2014 since their affiliation happened afterwards. Only FE regressions are presented for the sake of brevity, but pOLS estimations are available upon request.

Contrary to previous findings using the full sample (Column 2, Table 7), the relationship between innovation inputs and outputs changes its sign in Eurozone countries, although without attaining statistical significance (p = 0.2763). By analysing the five input pillars, only Business Sophistication revealed a positive statistically significant relationship with both Knowledge and Technology Outputs (O6) (Column 8, Table 9) and Creative Outputs (O7) (Column 9, Table 9), with p = 0.0678 and p = 0.0361, respectively. The relationship with Creative Outputs now visible, is in line with findings of Sohn, Kim and Jeon (2016). Although none of the remaining input pillars showed a statistically significant relationship with either Knowledge and Technology Outputs or Creative Outputs, their signs change according to the dependent variable used. While Institutions (I1), Human Capital and Research (I2), and Infrastructure (I3) showed a positive sign when regressed over Knowledge and Technology Outputs, those variables revealed a negative sign when regressed over Creative Outputs, with Market Sophistication (I4) having the opposite behaviour.

Next, we make a deeper analysis of the Eurozone sub-sample, by decomposing the five input pillars into their 15 input sub-pillars (Table 10) and using them as explanatory variables.

This detailed analysis reveals which sub-pillars are responsible for the results presented above in the Eurozone sub-sample. A negative and statistically significant relationship was found between Research and Development (I23) and Creative Outputs (p = 0.0013) (Column 15, Table 10), while the same statistical significance is not present regarding its relationship with Knowledge and Technology Outputs (O6), albeit remaining with a negative sign (Column 14, Table 10). This result could be due to different R&D sectors. Bilbao-Osorio and Rodriguez-Pose (2004) argue that public R&D may not be a net contributor to the innovation process since it is mainly associated with basic research. Ecological Sustainability (I33) shows a positive, statistically significant, relationship with Knowledge and Technology Outputs (p = 0.0048). This is in line with Cainelli et al. (2020), who suggest that environmental policies drive the adoption of eco-innovation by firms. Trade, Competition, and Market Scale (I43) also presents a positive and statistically significant relationship, below the 10% level, with Creative Outputs (p = 0.0718). Perhaps the most revealing result is the positive relationship, with a strong statistical significance, between Knowledge Absorption (I53) and both
Table 10. Results of Fixed Effects regressions using all input sub-pillars (Eurozone sub-sample)

| Dependent Variable | O6          | O7          |
|-------------------|-------------|-------------|
| Model             | FE (10)     | FE (11)     |
| I11               | 0.035       | 0.113       |
|                   | (0.116)     | (0.183)     |
| I12               | 0.023       | -0.151      |
|                   | (0.039)     | (0.095)     |
| I13               | 0.032       | 0.036       |
|                   | (0.067)     | (0.066)     |
| I21               | 0.025       | -0.005      |
|                   | (0.021)     | (0.032)     |
| I22               | -0.093      | -0.093      |
|                   | (0.090)     | (0.056)     |
| I23               | -0.042      | -0.165**    |
|                   | (0.033)     | (0.043)     |
| I31               | -0.014      | -0.065      |
|                   | (0.043)     | (0.043)     |
| I32               | -0.002      | -0.035      |
|                   | (0.097)     | (0.101)     |
| I33               | 0.163**     | 0.065       |
|                   | (0.051)     | (0.088)     |
| I41               | -0.047      | -0.003      |
|                   | (0.053)     | (0.072)     |
| I42               | 0.018       | -0.018      |
|                   | (0.055)     | (0.057)     |
| I43               | 0.168       | 0.205†      |
|                   | (0.108)     | (0.107)     |
| I51               | 0.037       | 0.078       |
|                   | (0.052)     | (0.077)     |
| I52               | -0.019      | -0.013      |
|                   | (0.059)     | (0.107)     |
| I53               | 0.228**     | 0.195**     |
|                   | (0.069)     | (0.041)     |
| N                 | 111         | 111         |
| Within R²         | 0.5795      | 0.6785      |
| BIC               | 478.036     | 544.667     |
| Time dummies      | Yes         | Yes         |
| Wald F (5, 18)    | 6.185**     | 9.807***    |

Source: Own calculation.

Note: † p ≤ 0.1; * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001. Below the coefficients are heteroskedasticity and autocorrelation (HAC) robust standard errors, in parenthesis. O6: Knowledge and technology outputs; O7: Creative outputs; I11: Political environment; I12: Regulatory environment; I13: Business environment; I12: Education; I12: Tertiary education; I13: Research and development; I13: Information and communication technologies; I13: General infrastructure; I13: Ecological sustainability; I41: Credit; I42: Investment; I43: Trade, competition, and market scale; I51: Knowledge workers; I52: Innovation linkages; I53: Knowledge absorption; FE: Fixed effects estimator.

Knowledge and Technology Outputs (p = 0.0041) and Creative Outputs (p = 0.0002). This is in line with the absorption capacity perspective (Cohen and Levinthal, 1990), in which the ability to recognise and incorporate external knowledge into the firm’s products and processes leads to higher levels of innovation (Gkypali et al., 2018).

Implications for Portugal

Following the results obtained in previous section, we now derive some policy implication for Portugal regarding improvements in its comparative levels of innovation. We start with a simple exercise, with which we intend to demonstrate the importance of certain policies on the convergence of Portugal with the Eurozone. First, we have selected the Knowledge Absorption sub-pillar due its significant effects on both innovations outputs and because it belongs to the pillar in which Portugal has a larger gap towards the Eurozone. Then, we have computed the difference between Portugal average score (25.356) and Eurozone’s (32.410) (averages for the period 2013-2018). The value was then multiplied by the estimated coefficient of Knowledge Absorption (I53) in each of the regressions presented in Table 10. The same reasoning was made for the top Eurozone performer, which, for this sub-pillar, is the Netherlands (48.441).

Table 11 shows potential benefits for innovation outputs if policies are developed to improve Business Sophistication areas in Portugal, namely those related to Knowledge Absorption. As mentioned above, Business Sophistication is the area where Portugal has a larger gap toward the Eurozone, having an average difference of 20% to other Eurozone countries and more than 35% to Eurozone top performers. Recalling Table 10, policies towards the attraction of FDI, or incentives to high-tech imports, are likely to enhance Portugal’s innovation output performance. However, caution must be taken when interpreting this results, since, as suggested by Liu and Zou (2008), different kinds of FDI might have differentiated effects on Portugal’s innovation performance. Another area where Portugal stands behind the Eurozone is Infrastructure. Results suggest that Ecological Sustainability has a
positive effect on Knowledge and Technology Outputs, hence, improving Portugal’s environmental performance, as well as having more firms with ISO 14001 certificates, could result in higher innovation outputs. Regarding negative relationships found, further research is needed to understand their causes before implications can be drawn.

CONCLUSIONS

With this paper we sought to understand which innovation inputs had a greater contribution to innovative outputs. In an effort to derive policy implication for Portugal, we narrowed our analysis to a group of countries that share innovation policies and regulations, as well their national currencies, with Portugal, the Eurozone. To that end, we have adopted the framework provided by the Global Innovation Index, due to its clear distinction between innovation inputs and outputs, and, acknowledging methodological limitations induced by its own cross-sectional nature, we have developed our own panel data version (DuCa framework).

Overall, results suggest some surprising negative relationships between Institutions, Human Capital and Research and innovation outputs. Such results should be taken with some caution, since those are areas where investments tend to require some years to pay off, as is the case of institutional change, education and R&D. Furthermore, Goedhuys et al. (2016) suggest that corruption can take the role of “grease in the wheels” when institutional obstacles are encountered, being otherwise an impediment to firm’s innovation in sound business environments. Positive relationships have also been found, namely in Business Sophistication area, which revealed to be stronger when analysing Eurozone alone. Further analyses revealed that those effects came essentially from areas such as the imports of high-tech goods, ICT services, and knowledge, as well as the presence of researchers in businesses and inward FDI. This suggest that the overall Knowledge Absorption of countries in the Eurozone is key in determining their innovative readiness.

Therefore, we argue that policies directed at improving domestic firms’ knowledge absorption capacity are likely to enhance Portugal’s innovative outputs, especially benefiting from the convergence to average Eurozone levels.

Limitations and Future Research

As with every research, our study has its limitations which ought to be acknowledged. The use of an index could be, in itself, a limitation. Nonetheless, we consider it a solid indicator of national innovativeness, since it blends hard data with experts’ opinions on a number of issues. Also, the GI is developed by some of the most important business and economics schools in cooperation with major international organisations.

The limited time period available impedes a longer analysis of the influence of certain variables, which we believe could have their impact felt further down the road. This limitation could be of extreme importance regarding the negative effects found throughout the paper, since investments in certain areas, such as education, R&D, or public infrastructures, might require several years to attain the desired outcome. As such, further research is necessary to explore the causes of negative relationships between innovation inputs and outputs found in this paper.

Another possibly relevant constraint is the absence of control variables, commonly found in this type of empirical analyses (e.g., Martins and Veiga, 2018). However, the indicators used in the construction of this index already contemplate the vast majority of controls used in the literature.

Lastly, research is needed regarding the most significant results of this study, the impact of Knowledge Absorption on both innovation outputs. Notwithstanding the other indicators relating to imports of goods, services, and knowledge, and the presence of researchers in businesses, we consider that inward FDI plays a major role in the innovative capacity of a country, mainly due to its dual effect on domestic firms: first, by increasing the competition in the local market, domestic firms tend to innovate to maintain their market position (Bertschek, 1995; Blind and Jungmittag, 2004); and second, different types of FDI could have differentiated effects on domestic firms capacity to innovate (Liu and Zou, 2008). Owing to the latter effect, Liu and Zou (2008) found that greenfield R&D FDI presented both intra- and inter-industry spillovers, while mergers and acquisitions produced only inter-industry spillovers. To derive more fine-grained policy implication to Portugal, one should rely on inward FDI data at the firm level, thus being able to control other firm’s factors that cannot be measured at the country level.

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Table 11. Estimated impact of Portugal’s convergence on the Knowledge Absorption sub-pillar with the Eurozone average and top performer

| Variable       | Estimated coefficient for Knowledge Absorption | Impact of convergence to the Eurozone average | Impact of convergence to the top Eurozone performer (Netherlands) |
|----------------|-----------------------------------------------|----------------------------------------------|---------------------------------------------------------------|
| O6 (Eurozone)  | 0.228                                         | 1.608                                        | 5.263                                                         |
| O7 (Eurozone)  | 0.195                                         | 1.376                                        | 4.502                                                         |

I. Source: Own calculations.

Note: O6: Knowledge and technology outputs; O7: Creative outputs.

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Table A1. Variables used, codes, definitions, sources and time-series

| Code  | Indicator | Definition | Source                                                                 | Period  |
|-------|-----------|------------|-----------------------------------------------------------------------|---------|
| 111   | Political stability and absence of violence / terrorism | Political stability and absence of violence / terrorism index | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 112   | Government effectiveness | Government effectiveness index | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 121   | Regulatory quality | Regulatory quality index | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 122   | Rule of law | Rule of law index | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 123   | Cost of redundancy dismissal | Sum of notice period and severance pay for redundancy dismissal (in salary weeks, averages for worker with 1, 5, 10 years of tenure, with a minimum threshold of 8 weeks) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 131   | Ease of starting a business | Ease of starting a business (distance to frontier) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 132   | Ease of resolving insolvency | Ease of resolving insolvency (distance to frontier) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 133   | Ease of paying taxes | Ease of paying taxes (distance to frontier) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2017 |
| 211   | Expenditure on education | Government expenditure on education (% of GDP) | [UNESCO Institute for Statistics](http://data.uis.unesco.org/#) | 2011 - 2016 |
| 212   | Initial government funding per secondary student | Initial government funding per secondary student (% of GDP per capita) | [UNESCO Institute for Statistics](http://data.uis.unesco.org/#) | 2011 - 2016 |
| 213   | School life expectancy | School life expectancy, primary to tertiary education, both sexes (years) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 214   | Assessment in reading, mathematics, and science | PISA average scores in reading, mathematics, and science | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 215   | Pupil-teacher ratio, secondary | Pupil-teacher ratio, secondary | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 221   | Tertiary enrolment | School enrolment, tertiary (% gross) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 222   | Graduates in science and engineering | Tertiary graduates in science, engineering, manufacturing, and construction (% of total tertiary graduates) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 223   | Tertiary-level inbound mobility | Tertiary-level inbound mobility rate (%) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 231   | Researchers | Researchers, full-time equivalent (FTE) (per million inhabitants) | [UNESCO Institute for Statistics](http://data.uis.unesco.org/#) | 2011 - 2016 |
| 232   | Gross expenditure on R&D (GERD) | GERD: Gross expenditure on R&D (% of GDP) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 233   | QS university ranking average score of top 3 universities | Average score of the top 3 universities at the QS world university ranking | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 311   | ICT access | ICT access index | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 312   | ICT use | ICT use index | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 313   | Government’s online service | Government’s online service index | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 314   | Online e-participation | E-participation index | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 321   | Electricity output | Electricity output (kWh per capita) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 322   | Logistics performance | Logistics Performance Index | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 323   | Gross capital formation | Gross capital formation (% of GDP) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 331   | GDP per unit of energy use | GDP per unit of energy use (2010 PPPS per kg of oil equivalent) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 332   | Environmental performance | Environmental Performance Index | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 333   | ISO 14001 environmental certificates | ISO 14001 Environmental management systems – Requirements with guidance for use: Number of certificates issued (per bn PPPS GDP) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 411   | Ease of getting credit | Ease of getting credit (distance to frontier) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 412   | Domestic credit to private sector | Domestic credit to private sector (% of GDP) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 413   | Microfinance institutions’ gross loan portfolio | Microfinance institutions: Gross loan portfolio (% of GDP) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |
| 421   | Ease of protecting minority investors | Ease of protecting minority investors (distance to frontier) | [Global Innovation Index](https://www.globalinnovationindex.org/analysis-indicator) | 2013 - 2018 |

Source: Own elaboration.
| Code  | Indicator                                      | Definition                                                                                      | Source                                                                 | Period       |
|-------|-----------------------------------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|--------------|
| 422   | Market capitalisation                         | Market capitalisation of listed domestic companies (% of GDP)                                     | World Bank, World Development Indicators                                | 2012 – 2017  |
| 423   | Total value of stocks traded                  | Stocks traded, total value (% of GDP)                                                            | World Bank, World Development Indicators                                | 2012 – 2017  |
| 424   | Venture capital deals                         | Venture capital per investment location: Number of deals (per bn PPPS GDP)                      | Global Innovation Index                                                 | 2013 – 2018  |
| 431   | Applied tariff rate, weighted mean            | Tariff rate, applied, weighted mean, all products (%)                                           | Global Innovation Index                                                 | 2013 – 2018  |
| 432   | Intensity of local competition                | Average answer to the survey question: In your country, how intense is the competition in the local markets? [1 = not intense at all; 7 = extremely intense] | Global Innovation Index                                                 | 2013 – 2018  |
| 433   | Domestic market scale                         | Domestic market as measured by GDP, PPP (current international $)                               | World Bank, World Development Indicators                                | 2012 – 2017  |
| 511   | Employment in knowledge-intensive services    | Employment in knowledge intensive services (% of workforce)                                     | International Labour Organization ILOSTAT                                | 2012 – 2017  |
| 512   | Firms offering formal training                | Firms offering formal training (% of firms)                                                     | Global Innovation Index                                                 | 2013 – 2018  |
| 513   | GERD performed by business enterprise         | GERD: Performed by business enterprise (% of GDP)                                               | UNESCO Institute for Statistics                                          | 2011 – 2016  |
| 514   | GERD financed by business enterprise          | GERD: Financed by business enterprise (% of total GERD)                                         | UNESCO Institute for Statistics                                          | 2011 – 2016  |
| 515   | Females employed with advanced degrees        | Females employed with advanced degrees, % of total employed (25+ years old)                    | International Labour Organization ILOSTAT                                | 2012 – 2017  |
| 521   | University / industry research collaboration  | Average answer to the survey question: In your country, to what extent do businesses and universities collaborate on research and development (R&D)? [1 = do not collaborate at all; 7 = collaborate extensively] | Global Innovation Index                                                 | 2013 – 2018  |
| 522   | State of cluster development                  | In the economy: In your country, how widespread are well-developed and deep clusters (geographic concentrations of firms, suppliers, producers of related products and services, and specialized institutions in a particular field)? [1 = non-existent; 7 = widespread in many fields] | Global Innovation Index                                                 | 2013 – 2018  |
| 523   | GERD financed by abroad                       | GERD: Financed by abroad (% of total GERD)                                                      | Global Innovation Index                                                 | 2013 – 2018  |
| 524   | Joint venture / strategic alliances deals     | Joint ventures / strategic alliances: Number of deals, fractional counting (per bn PPPS GDP)   | Global Innovation Index                                                 | 2013 – 2018  |
| 531   | Intellectual property payments                | Charges for use of intellectual property n.i.e., payments (% of total trade)                   | World Trade Organization                                                | 2012 – 2017  |
| 532   | High-tech imports                            | High-tech net imports (% of total trade)                                                        | United Nations Comtrade database                                        | 2012 – 2017  |
| 533   | ICT services imports                          | Telecommunications, computers, and information services imports (% of total trade)             | World Trade Organization                                                | 2012 – 2017  |
| 534   | Foreign direct investment net inflows         | Foreign direct investment (FDI), net inflows (% of GDP)                                         | World Bank, World Development Indicators                                | 2012 – 2017  |
| 535   | Research talent in business enterprise        | Researchers in business enterprise (%)                                                          | UNESCO Institute for Statistics                                          | 2011 – 2016  |
| 611   | Patent applications by origin                 | Number of resident patent applications filed at a given national or regional patent office (per bn PPPS GDP) | Global Innovation Index                                                 | 2013 – 2018  |
| 612   | PCT international applications by origin      | Number of international patent applications filed by residents at the Patent Cooperation Treaty (per bn PPPS GDP) | Global Innovation Index                                                 | 2013 – 2018  |
| 613   | Utility model applications by origin          | Number of utility model applications filed by residents at the national patent office (per bn PPPS GDP) | Global Innovation Index                                                 | 2013 – 2018  |
| 614   | Scientific and technical publications         | Number of scientific and technical journal articles (per bn PPPS GDP)                          | Global Innovation Index                                                 | 2013 – 2018  |
| 615   | Citable documents H index                     | The H index is the economy’s number of published articles (H) that have received at least H citations | Global Innovation Index                                                 | 2013 – 2018  |
| 621   | Growth rate of GDP per person engaged         | Growth rate of GDP per person engaged (constant 2011 PPPS)                                      | Global Innovation Index                                                 | 2013 – 2018  |
| 622   | New business density                         | New business density (new registrations per thousand population 15–64 years old)               | Global Innovation Index                                                 | 2013 – 2018  |
| 623   | Total computer software spending              | Total computer software spending (% of GDP)                                                     | Global Innovation Index                                                 | 2013 – 2018  |

Source: Own elaboration.
Table A1 (continued). Variables used, codes, definitions, sources and time-series

| Code | Indicator | Definition | Source |
|------|-----------|------------|--------|
| 624  | ISO 9001 quality certificates | ISO 9001 Quality management systems—Requirements: Number of certificates issued (per bn PPP$ GDP) | [https://www.globalinnovationindex.org/analysis-indicator](https://www.globalinnovationindex.org/analysis-indicator) |
| 625  | High-tech and medium-high-tech output | High-tech and medium-high-tech output (% of total manufactures output) | [https://www.globalinnovationindex.org/analysis-indicator](https://www.globalinnovationindex.org/analysis-indicator) |
| 631  | Intellectual property receipts | Charges for use of intellectual property n.i.e., receipts (% of total trade) | World Trade Organization [https://data.wto.org/] |
| 632  | High-tech exports | High-tech net exports (% of total trade) | [https://comtrade.un.org/data/](https://comtrade.un.org/data/) |
| 633  | ICT services exports | Telecommunications, computers, and information services exports (% of total trade) | World Trade Organization [https://data.wto.org/] |
| 634  | Foreign direct investment net outflows | Foreign direct investment (FDI), net outflows (% of GDP) | World Bank, World Development Indicators [https://databank.worldbank.org/data/source/world-development-indicators](https://databank.worldbank.org/data/source/world-development-indicators) |
| 711  | Trademark application class count by origin | Number of trademark applications issued to residents at a given national or regional office (per billion PPP$ GDP) | World Intellectual Property Organization, WIPO Statistics Database [https://www3.wipo.int/ipstats/index.htm](https://www3.wipo.int/ipstats/index.htm) |
| 712  | Industrial designs by origin | Number of designs contained in industrial design applications filed at a given national or regional office (per billion PPP$ GDP) | World Intellectual Property Organization, WIPO Statistics Database [https://www3.wipo.int/ipstats/index.htm](https://www3.wipo.int/ipstats/index.htm) |
| 713  | ICTs and business model creation | Average answer to the question: In your country, to what extent do ICTs enable new business models? [1 = not at all; 7 = to a great extent] | [https://www.globalinnovationindex.org/analysis-indicator](https://www.globalinnovationindex.org/analysis-indicator) |
| 714  | ICTs and organizational model creation | Average answer to the question: In your country, to what extent do ICTs enable new organizational models (e.g., virtual teams, remote working, telecommuting) within companies? [1 = not at all; 7 = to a great extent] | [https://www.globalinnovationindex.org/analysis-indicator](https://www.globalinnovationindex.org/analysis-indicator) |
| 721  | Cultural and creative services exports | Cultural and creative services exports (% of total trade) | World Trade Organization [https://data.wto.org/](https://data.wto.org/) |
| 722  | National feature films produced | Number of national feature films produced (per million population 15–69 years old) | Global Innovation Index [https://www.globalinnovationindex.org/analysis-indicator](https://www.globalinnovationindex.org/analysis-indicator) |
| 723  | Entertainment and media market | Entertainment and media market (per thousand population 15–69 years old) | Global Innovation Index [https://www.globalinnovationindex.org/analysis-indicator](https://www.globalinnovationindex.org/analysis-indicator) |
| 724  | Printing publications and other media output | Printing publications and other media (% of manufactures total output) | Global Innovation Index [https://www.globalinnovationindex.org/analysis-indicator](https://www.globalinnovationindex.org/analysis-indicator) |
| 725  | Creative goods exports | Creative goods exports (% of total trade) | United Nations Comtrade database [https://comtrade.un.org/data/](https://comtrade.un.org/data/) |
| 731  | Generic top-level domains (gTLDs) | Generic top-level domains (gTLDs) (per thousand population 15–69 years old) | Global Innovation Index [https://www.globalinnovationindex.org/analysis-indicator](https://www.globalinnovationindex.org/analysis-indicator) |
| 732  | Country-code top-level domains (ccTLDs) | Country-code top-level domains (ccTLDs) (per thousand population 15–69 years old) | Global Innovation Index [https://www.globalinnovationindex.org/analysis-indicator](https://www.globalinnovationindex.org/analysis-indicator) |
| 733  | Wikipedia monthly edits | Wikipedia monthly page edits (per million population 15–69 years old) | Global Innovation Index [https://www.globalinnovationindex.org/analysis-indicator](https://www.globalinnovationindex.org/analysis-indicator) |
| 734  | Video uploads on YouTube | Number of video uploads on YouTube (scaled by population 15–69 years old) | Global Innovation Index [https://www.globalinnovationindex.org/analysis-indicator](https://www.globalinnovationindex.org/analysis-indicator) |

Source: Own elaboration.
| Table A2. Countries in the sample |
|----------------------------------|
| Albania                          | Egypt | Kyrgyz Republic | Romania         |
| Algeria                          | Estonia | Latvia          | Russian Federation |
| Argentina                        | Finland | Lithuania      | Saudi Arabia |
| Armenia                          | France | Luxembourg      | Senegal         |
| Australia                        | Georgia | Madagascar     | Serbia          |
| Austria                          | Germany | Malaysia       | Singapore       |
| Azerbaijan                       | Greece | Malta          | Slovak Republic |
| Algeria                          | Guatemala | Mauritius | Slovenia |
| Bangladesh                       | Hong Kong | Mexico | South Africa |
| Belarussia                       | Hungary | Moldova       | Spain           |
| Belgium                          | Iceland | Mongolia       | Sri Lanka       |
| Bolivia                          | India | Morocco        | Sweden          |
| Bosnia and Herzegovina           | Indonesia | Netherlands | Switzerland |
| Brazil                           | Iran | New Zealand | Tajikistan |
| Bulgaria                         | Ireland | Nigeria | Thailand |
| Canada                           | Israel | North Macedonia | Tunisia |
| Chile                            | Italy | Norway         | Turkey          |
| China                            | Jamaica | Pakistan | Uganda |
| Colombia                         | Japan | Panama        | Ukraine         |
| Costa Rica                       | Jordan | Peru          | United Kingdom |
| Cyprus                           | Kazakhstan | Philippines | United States of America |
| Czech Republic                   | Kenya | Poland        | Uruguay         |
| Denmark                          | Korea, Republic of | Portugal | Vietnam |

Source: Own elaboration.