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Does scientific research output matter for Portugal's economic growth?

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Does scientific research output matter for Portugal's economic growth? [1]

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Abstract

The literature on the impact of research output on economic growth has been rapidly expanding. However, the single growth processes of technological laggard countries and the mediating roles of human capital and structural change have been overlooked.

Resorting to cointegration analyses and Granger causality tests for Portugal over the last 40 years (1980-2019) four main results are worth highlighting: (1) in the long-run, global and hard sciences (life sciences, physical sciences, engineering and technology, social sciences) research outputs are positively and significantly associated to economic growth; (2) in the short-run, global, hard sciences and soft sciences (base clinical, pre-clinical and health, arts and humanities) foster economic growth; (3) important (long and short-run) mismatches between human capital and scientific production emerged, with the years of schooling mitigating the positive impact of research output on economic growth; (4) structural change processes favouring industry amplify the positive (long-run) association and (short-run) impact of research output on economic growth.

Such results robustly suggest that even in technological laggard contexts, scientific production is critical for economic growth, especially when aligned with changes in sectoral production composition favouring industry.

JEL-Codes: O30; O38; O47

Keywords: Research output; human capital; structural change; economic growth; cointegration analysis; Portugal

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1. Introduction

New and advanced knowledge produced through research activity can foster development and economic growth (Jaffe et al. 2020, Yang and Liu 2020). Scientific research creates new knowledge (Inglesi-Lotz and Pouris, 2013), acts as a source of innovation, and thus leads to enhancements in the productive capacity and labour quality, which are conducive to economic growth (Hatemi-J et al. 2016; Ntuli et al. 2015).

The impact of research output on economic growth is a key element in terms of a science policy, that allows to define the research priorities and understand the efficacy of R&D investment (Inglesi-Lotz and Pouris, 2013; Lee et al. 2011). Consequently, whether research output significantly impacts on economic growth, and which research areas/ fields of science matter the most to improve economic performance, stand fundamental endeavours of scientific inquiry (Pinto and Teixeira, 2020).

Most of the extant literature that explored the impact of the research output on the economic growth using a single country basis of analysis have addressed very well positioned countries in terms of science from Europe (e.g., Germany, Netherlands, Switzerland, UK), America (e.g., Canada, US), Asia (e.g., Japan, Singapore, South Korea, Taiwan) and Oceania (e.g., Australia) (Lee et al. 2011; Inglesi-Lotz et al. 2014; Ntuli et al. 2015), as well as emerging economies such as Brazil, Russia, India, China, and South Africa (Lee et al. 2011; Inglesi-Lotz et al. 2015). Moreover, these empirical studies analysed the research output in global terms without discriminating the diverse areas of the research (Inglesi-Lotz et al. 2014) or focused on a specific field of the research, such as Economics (Jin 2010), and Biotechnology (Yasgül and Güris 2016), basic science and engineering and Economics and business (Jin and Jin 2013) and sciences and social sciences (Zaman et al. 2018). To the best of our knowledge, no study has yet explored the impact of the research output by the different areas of the research using a single country analysis, most notably focusing on countries far from the science frontier such as Portugal.

The Portuguese case can be scientifically interesting because on the one side it provides evidence of a context characterized by some laggardness in terms of technology and innovation performance (Teixeira and Fortuna 2004, 2010); one the other side, it has experienced noticeable dynamics in terms of research output (Heitor and Bravo 2010; Heitor et al. 2014), albeit its performance in terms of human capital and structural change has been debatable (Teixeira et al. 2014; Rebelo and Silva 2017).

Despite the apparent dynamics in terms of scientific output, the studies that have analysed Portuguese economic growth overlooked such growth factor. Indeed, the literature on the Portuguese economic growth has explored diverse groups of determinants (see Table A1, in Annex) related to the macroeconomic conditions (e.g. investment, physical capital, inflation), international trade (e.g., exports, imports, FDI), demography and labor force (e.g., employment, life expectancy, infant mortality), and institutional conditions (e.g., financial development, corruption), but failed to scrutinize the extent to which the research output dynamics has contributed to economic growth.

The present study aims to contribute to fill this gap by undertaking an empirical analysis of the long-term relation (and eventual impact) of research output (globally and by fields of science) and (on) Portugal's economic growth. We further consider the mediating role of human capital and structural change in this relation as it is expected that the impact of research output on economic growth might be influenced by the level of human capital (Silva and Teixeira 2011) and the productive specialization profile of the economy (Teixeira and Queirós 2016). It is crucial to understand which types of research are aligned with the countries' absorptive capacity and pace of structural change from a scientific and policymaker's point of view. Such impacts have not yet been empirically tested.

Methodologically, in the line with the existing studies in this area (e.g., Jin 2009, 2010, Lee et al. 2011), we resort to cointegration and Granger causality analyses, involving time series of real GDP per capita, research output by areas of research, human capital and structural change, from 1980 to 2019.

This paper is organized as follows. Section 2 summarizes the relevant literature. Section 3 defines and discusses the methodology. The empirical results are detailed in Section 4. Finally, the Conclusions put forward the study's main contributions, limitations, and policy implications.

2. The impact of research output on economic growth: A literature review considering the mediating role of human capital and structural change

2.1 Initial considerations

The uncovering of the main determinants of countries' economic performance has been object of many studies (e.g., Sala-i-Martin et al. 2004; Durlauf et al. 2005; Ciccone and Jarociński 2010; Moral-Benito 2012; Bruns and Ioannidis 2020) being a critical topic for policy makers (He and Xu 2019).

The relevant literature has identified a vast number of economic growth determinants. For instance, departing from a large number (32) of potential economic growth determinants, Sala-i-Martin et al. (2004) found that one third (11) were robustly correlated with long-term economic growth. Durlauf et al. (2005) identified 145 potential growth determinants, whereas Moral-Benito (2012) identified 34 determinants. Such large and diversified set of determinants obliged authors to organize them into meaniful groups. Based on several key studies, economic growth determinants can be grouped into 7 groups (see Table A2 in Annex): 1) Science, technology and innovation; 2) Human capital and skills; 3) International trade and FDI; 4) Labor and demographic conditions; 5) Macroeconomic conditions; 6) Institutions; and 7) Natural resources and geography.

2.2. The impact of RO on economic growth: main hypotheses

The idea that the accumulation of knowledge plays a central role in economic growth is not new (Bhullar and Kaur 2014). Long ago, Adam Smith and Alfred Marshall proposed a system that incorporated knowledge accumulation in the production process (Quatraro 2010) and Schumpeter (1912, 1942) identified knowledge as a channel to achieve innovation that would countribute to economic performance (Saviotti and Pyka 2004).

Scientific research output most notably, codified knowledge associated to scientific publications (Kumar et al. 2016; Solarin and Yen 2016), is one of the channels that creates new knowledge (Inglesi-Lotz and Pouris 2013; Ntuli et al. 2015; Yasgul and Güriş 2016). Such knowledge is likely to induce positive externalities on the productive capacity of economies (Schumpeter 2000, Inglesi-Lotz and Pouris 2013; Inglesi-Lotz et al. 2013), generating innovation and, ultimately, leading to economic growth (Pegkas et al. 2019). Additionally, the volume of research activities shows the capabilities of a country's labor force and the attractiveness of the economy in terms of foreign and domestic investments (Kumar et al. 2016).

The relationship between knowledge and economic growth can be formally explained in mainstream economic theories, and the neoclassical and endogenous growth theories (or New Growth Theory) (Solarin and Yen 2016). In the first theory, knowledge associated to technology is exogenous, emerging as 'manna from heaven' (Solow, 1956). In the New Growth Theory or Endogenous Growth theory, knowledge is considered as an input that is endogenously produced through Research and Development (R&D) incentives (Romer 1986). Thus, rising R&D, which in large part is constituted by scientific production (basic R&D), contributes to innovation and economic growth.

Albeit the importance of knowledge for economic growth was recognized at the theoretical level from a long ago, empirically the literature on economic growth only more recently started paying attention to the impact of knowledge in its research output dimension on economic growth (e.g., Pinto and Teixeira 2020; Kumar et al. 2016; Solarin and Yen 2016; Yasgul and Güriş 2016). Several studies have identified a positive relationship with causality running from research output to economic growth (e.g., Lee et al. 2011, Inglesi-Lotz et al. 2014, Ntuli et al. 2015, Solarin and Yen 2016). The investment in R&D activities promotes the production of the research output that is an open source for innovation (Inglesi et al. 2015; Ntuli et al 2015; Solarin and Yen 2016) that can lead to higher economic growth by the increase of productivity and labour (Ntuli et al 2015; Solarin and Yen 2016).

The current ongoing debate about countries' economic growth and research output has been related to which area of scientific knowledge is better to promote economic growth (Jaffe et al. 2020; Pinto and Teixeira 2020; Antonelli and Fassio 2016). Different areas of knowledge are likely to impact distinctly on countries' economic growth (Rai and Lal 2000; Jin and Jin 2013 and Yasgul and Güriş 2016).

Following the framework of Antonelli and Fassio (2016), we can identify two main types of (scientific) knowledge: 'capital good' and 'final good'. Capital knowledge works as an "intangible capital and intermediary inputs", i.e., as a necessary input into the production of other goods (Antonelli and Fassio 2016, 559). Promoting this type of knowledge can foster technological change and might lead to the increase in economic growth, as it is characterized by high levels of appropriation and wider scope of application. Such knowledge is usually associated to hard (e.g., life and physical sciences, engineering and technology) and social (e.g., economics and business) sciences (Antonelli and Fassio 2016). The knowledge produced by hard sciences is likely to contribute most to economic growth because it leads directly to the introduction of technological innovations in a wide array of industries; and social science-related knowledge fosters organizational innovations and improvements in business practices, being fundamental to economic growth (Antonelli and Fassio 2016).

The second type of knowledge that can be treated as 'final good' and has low levels of appropriation and limited capacity for application and it is often associated to humanities and/ or in medical sciences. Its impact on economic growth is small when compared with the previous type of knowledge as it tends to contribute mostly to the increase of the utility of final consumers instead of directly increasing the economic growth (Antonelli and Fassio 2016).

Complementarily, Jaffe et al. (2013, 2020) demonstrated that higher productivity in basic sciences, namely physics and chemistry, induces stronger impact on economic growth when comparing with the relative lower productivity, and lower growth impact, of applied sciences, most notably medicine and pharmacy.

Based on the above, we conjecture that:

H1: At the country level, the overall research output tends to impact on economic growth positively.

H1a: The impact of research output on economic growth is likely to be higher in fields of science where knowledge is similar to a capital good than in fields of science where it resembles a final good.

2.3. RO and economic growth: The mediating role of human capital and structural change: further hypotheses

An economy characterized by high levels of human capital (education/ training) tends to be more productive (Bodman and Le 2013; Wößmann 2003), leveraging economic growth (Jin and Jin, 2013). The theoretical models of human capital (Becker 1962, Mincer 1958; Schultz 1961) establish that investment in knowledge and human capital can directly lead to increases in productivity and, consequently, raise economic growth. Indirectly, human capital can interact with research output operating as a productivity booster for research activities that stimulate research output (Pinto and Teixeira 2020; Silva and Teixeira 2011). Countries with a higher level of human capital are possible more efficient in performing R&D activities, that lead to higher levels of research output/ knowledge (Romer 1990; Teixeira and Fortuna 2010; Bodman and Le 2013; Teixeira and Queirós 2016, Pinto and Teixeira, 2020).

According to Inglesi-Lotz and Pouris (2013), the channel that can explain the impact of the improvement in human capital on economic growth, through research output is the following: better human capital leads to improvements in the production of research, that generate more and/or better knowledge basis and consequently promote economic growth.

Thus, we hypothesize that:

H2: High levels of human capital enhance the impact of research output (global and field related) on economic growth.

Structural change, defined as a change in the economy's productive structure (Quatraro 2010), is considered as an important determinant of economic growth (Silva and Teixeira 2011). The effect can be direct (Frantzen 2000; Quatraro 2009, 2010; Wolff 2003) or indirect through the production of research output (Leydesdorff and Wagner 2009, Pinto and Teixeira, 2020). This occurs essentially, when there is a match between change in productive structure, for instance when the weight of a given sector in total employment or output, and the evolution of research output by scientific areas match is likely to enhance the impact of research output on economic growth (Quatraro 2010; Silva and Teixeira 2011). By match we mean that the research activities developed in a country are aligned with the current needs of the industries, working closely can revitalize the ideas and knowledge allowing to achieve higher economic performance.

We thus hypothesize that:

H3: Structural change towards industry can boost the impact of research output (global and field related) on economic growth.

2.4. The impact of RO on economic growth: synthesis of the empirical results

2.4.1. Global research output

The literature that focuses on the impact of research output on economic growth analyzed it mainly in global terms (see Inglesi-Lotz et al. 2015; Ntuli et al. 2015; Solarin and Yen 2016 Onyancha, 2020), or focusing on a restricted number of specific fields of research, such as chemical engineering (Hart and Sommerfeld 1998), economics (Jin 2009, 2010), biotechnology (Yasgül and Güris 2016), basic science and engineering and Economics and business (Jin and Jin 2013) and sciences and social sciences (Zaman et al. 2018).

Such literature includes both studies that focused on large samples of countries (e.g., Jin 2009, Lee et al. 2011, Inglesi-Lotz et al. 2015, Ntuli et al. 2015, Hatemi-J et al. 2016, Kumar et al. 2016, Dkhili and Oweis 2018, Zaman et al. 2018) and studies that analyze countries individually (e.g., Jin 2010, Inglesi-Lotz and Pouris 2013, Inglesi-Lotz et al. 2014, Odhiambo and Ntenga 2016, Yasgül and Güris 2016).

The former set of studies encounter a positive relationship between research output and economic growth. Indeed, based on a large sample of (169) countries, and using System GMM, Solarin and Yen (2016) found a positive impact of the number of articles in journals (research output) on real per capita GDP (the proxied used for economic growth) over the period of 1996-2013. A similar positive relationship was observed for Latin-American countries (De Moya-Anegón and Herrero-Solana 1999). Based on a specific area of research, chemical engineering, Hart and Sommerfeld (1998) showed that publications have a strong positive correlation with economic growth in 5 countries US, Canada, Great Britain, Australia, and India.

Regarding the studies that used research output in global terms and analyze the countries individually, it is possible to find some examples of uni-direction causality from research output to economic growth (Lee et al. 2011, Inglesi-Lotz et al. 2015, Ntuli et al. 2015, Hatemi-J et al. 2016). Lee et al. (2011), using time-series methodologies analyzed individually 25 countries between the period 1981 to 2007. Their results evidence that the causality ran from research output, measured by the number of publications, to economic growth, measured by nominal GDP, in the case of Austria, Australia, Germany, Netherlands and India despite these countries' present different competitive advantages in scientific research. Similar results were found by Inglesi-Lotz et al. (2015) for India, which is often considered a new emerging R&D destination for international projects in different areas of research and stands among the fastest-growing emerging countries BRICS (Wharton 2005). In their analysis, Inglesi-Lotz et al. (2015) used the bootstrap panel Granger causality approach for the period ranging between 1981 and 2011. These authors considered the real GDP, instead of the nominal GDP used in Lee et al. (2011), and the research output was measured by the share of a number of publications of the country to the rest of the world. In contrast to Lee et al. (2011), who have found a causality effect from research output to economic growth for Austria, Australia, Germany, and the Netherlands, Ntuli et al. (2015) found no causality on that direction for those countries and Hatemi-J et al. (2016) for the Germany case. Such a disparate result can be related to the differences in the measurement of economic growth (nominal versus real GDP).

Using the same method and period of Inglesi-Lotz et al. (2015), Ntuli et al. (2015) found positive causality from research output (total number of articles published) to economic growth for Finland, Hungary, Mexico, and the US. The latter country was also analysed by Inglesi-Lotz et al. (2014) who again encounter a positive causality running from research output (share of the number of publications of the country to the rest of the world) to economic growth, for a similar period using also a Granger causality relationship indicated by the bootstrap rolling causality tests. Contrary, the reverse direction of the causality, i.e., from economic growth to economic growth was found by Lee et al. (2011) and Kumar et al. (2016), the later used research publications per worker to proxy the research output and real GDP per worker for economic growth between the period of 1981 to 2012 evaluating China and US case by cointegration analyses. Hatemi-J et al. (2016) from 1981 to 2012, found no causality for almost all the G7 countries including the United States, Canada, France, Germany Japan and Italy.

The United Kingdom is another case in which is found some discrepancies between studies: Hatemi-J et al. (2016) found causality from research output to economic growth, whereas the reverse direction was found by Ntuli et al. (2015), and no causality was found by Leet et al. (2011). The same happens in the case of Turkey with Yasgül and Güris (2016) found causality from research output to economic growth, whereas the study of Inglesi-Lotz et al. (2015) and Ntuli et al. (2015) found no causality.

Exploring the case of South Africa, Inglesi-Lotz and Pouris (2013) and Odhiambo and Ntenga (2016) found causality from research output to economic growth. In contrast, Inglesi-Lotz et al. (2015) using the same proxy of Inglesi-Lotz and Pouris (2013) but with a wider period (1981 to 2011) found no causality for South Africa.

In a nutshell, and based on the extant empirical evidence, it is not possible to establish a clear relationship between the level of income, the scientific performance or level of technology of each country and the direction of the causality between research output and economic growth (see Table A3 in annex).

2.4.2. Research output by areas

Concerning the small set of studies that analyses research output by areas – Economics, biotechnology, sciences and social sciences - and countries individually evidence was found that in the field of Economics and for 5 East Asian (South Korea, Taiwan, Hong Kong, Japan and Singapore) countries between 1969 to 2004, causality ran from research output (publication per million people in Economics) to economic growth (nominal GDP) only in the case of South Korea and Taiwan (Jin 2009). According to the author, such an outcome is consistent with countries' investment in purchasing overseas publications to be competitive with foreign universities. Exploring just the case of Japan, for the period of 1970 to 2004 Jin (2010) found causality running from economic growth to research output as in his previous study (Jin 2009).

Regarding the relation between Turkish economic growth and its Biotechnology research output over the period, 1981 to 2013, Yasgül and Güris (2016) found, resorting to bootstrapped Granger causality analysis, that causality ran from research output to economic growth. That means that the research output in the field of biotechnology is one of the factors that lead to economic growth for the period in analyses. According to the authors, this field of research involves new technologies, requires interdisciplinary research and potential dissemination to the traditional sectors generating economic growth.

Exploring the relationship between research productivity (number of publications in sciences and social sciences, research & development (R&D), expenditures and researchers involved in R&D activities) with the economic growth (real GDP) using Cointegration and Granger Causality between 1980 to 2011, Zaman et al. (2018) found causality from that the number of publication in sciences and social sciences to the economic growth in Turkey, Russia, South Korea, Canada, UK, China.

2.4.3. Empirical evidence for Portugal

Several studies have addressed Portugal's long-term growth (see Table A1, in Annex), in isolation at the aggregate/ national (e.g., Bação, Gaspar and Simões, 2019; Santos, Domingos, Sousa and Aubyn, 2018) or regional levels (Manso, Matos and Carvalho, 2015), and combined with other countries (e.g., Santosa and Catalão-Lopes, 2014; Kónya, 2006). However, the majority of such studies has focused on determinants not specifically related to research output. In fact, those studies focused mainly on determinants related to macroeconomic conditions (e.g., Shahbaz, Benkraiem et al. 2017; Santos et al. 2018), international trade (Andraz and Rodrigues 2010; Rebelo and Silva 2017), and labour and demographic conditions (Morgado, 2014).

In general, it was found that the investment rate (Rei, 2007, Marques, Fuinhas and Marques, 2013), level of investment (Shahbaz et al. 2013; Shahbaz et al. 2017) or physical capital accumulation (Pereira and Pinho, 2008) positively influenced economic growth regardless the proxy used for growth (growth rate of the GDP per capita - Rei, 2007; the level of the GDP per capita – Shahbaz et al. 2013; Shahbaz et al. 2017; the level of GDP - Pereira and St Aubyn 2009; Marques, Fuinhas and Marques 2013; Morgado 2014). Moreover, international trade revealed a positive impact on economic growth, regardless how it was measured - trade openness (Shahbaz et al. 2013), exports (Ramos, 2001; Andraz and Rodrigues, 2010), imports (Ramos, 2001) or FDI (Andraz and Rodrigues, 2010). Analyzing the period 1960-2005, and resorting to cointegration and Granger causality, Morgado (2014) encountered a positive causality running from economic growth (GDP) to life expectancy and a negative causality running from economic growth to infant mortality.

Focusing on the regional level analysis (NUTS III), and the period between 1999 and 2010, Manso, Matos and Carvalho (2015) explored different determinants to explain economic growth using a random-effects model. The authors conclude that employment per sector of activity ('Labor market'), sectorial GVA ('Productivity'), electricity consumption ('Energy'), number of periodicals ('Culture'), and landline phone ('Technology') lead to regional economic growth.

Although no study exists about Portuguese economic growth that explored the impact of research output/ scientific knowledge, Teixeira and Fortuna (2004), resorting to vector autoregressive and cointegration analysis, have assessed the impact of R&D, which includes research output, on Portuguese's long-run growth between 1960 and 2001. The authors concluded that R&D intensity, which reflected indigenous innovation efforts, was extremely important to the economic growth process in Portugal during that period. Moreover, Teixeira and Fortuna (2004, 2011) demonstrated that human capital enhanced the impact of internal stock of knowledge/ innovation capability and the imports of advanced technology from abroad on economic growth. In a nutshell, human capital acted as a mediating factor of the relation between the internal stock of knowledge/ innovation capability/ the imports of advanced technology from abroad and economic growth.

Regarding the structural change some studies identified it as a critical factor for Portuguese economic growth (e.g., Rocha 1997, Lains 2008). Concerning the period of 1960-1970, the structural change (increases in industry and decreases in agriculture employment/ product shares) is related to the acceleration of Portuguese economic growth (Rocha 1997). Analyzing the period between 1960 and 2004, Lains (2008) evidenced that in Portugal and Ireland the change of the structure of employment occurred by the reduction in the share of the labour force employed in traditional sectors (e.g., agriculture, forestry, fishing; textiles, leather, footwear and clothing; food, drink and tobacco) and by an increase in shares of modern sectors (e.g., non-market services, other services). This transformation occurred faster in Ireland than in Portugal. Additionally, it was observed that the share of ICT producing and using industries in the manufacturing and the service sectors was faster in Ireland comprising 25.4% of the labour force in 1979, and 33.5%, in 2002. In Portugal, the corresponding share was below 22.1%, in 1979, and 25.4%, in 2002. Lains (2008) doing a shift-share analysis of labour productivity growth with the following components: intra-industry effect, static effect and dynamic effect concluded that the dynamic effect impacted negatively on labour productivity growth. This result was related to the fact that Portugal had comparative advantages in sectors with lower levels of labour productivity. Due to the increase in the exposition to international market forces, which resulted from the abandonment of tariff protection and the adoption of the Euro, the output of those lower productivity industries increased. Moreover, Portugal had a lower endowment in physical and human capital.

3. Methodological considerations

3.1. Main hypotheses and econometric specification

The main purpose of this study is to evaluate the impact of research output, global and by area of research (proxied by the number of publications per 1000 inhabitants), on Portuguese economic growth (real GDP per capita) mediated by human capital and structural change, from 1980 to 2019.

Existing research on the effects of research output on economic growth of individual countries use both single (Jin, 2010; Inglesi-Lotz and Pouris, 2013; Inglesi-Lotz et al., 2014; Odhiambo and Ntenga, 2016; Yasgül and Güris, 2016) and multi-country samples (Jin, 2009; Lee et al., 2011; Kumar et al., 2016; Zaman et al., 2018), involving the analysis of annual time series. Such research has applied different methods of analysis: VAR (Lee et al., 2011; Inglesi-Lotz et al., 2014; Zaman et al., 2018); Cointegration (Johansen tests) and Granger causality (Yasgül and Güris, 2016), and Autoregressive Distributed Lag (ADRL) (Inglesi-Lotz and Pouris, 2013; Kumar et al., 2016; Odhiambo and Ntenga, 2016).

Independently of the approach used, the starting point in the time series analysis is identifying whether the time series data is stationary or non-stationary, that is, if its value tends to revert to its long-run average value or not. For such assessment, researchers resort to unit root tests, most notably the Augmented Dickey-Fuller (Dickey and Fuller, 1981), the Phillips-Perron (Phillips and Perron, 1988), and the KPSS tests (Kwiatkowski Phillips, Schmidt and Shin,1992).

The method and models of time series analysis are selected according to the results of the previous tests. When all variables are stationary, it is possible to apply the OLS (Ordinary least square) or VAR (Vector Autoregressive) estimation techniques (Shrestha and Bhatta, 2018). If the variables are non-stationary, OLS and VAR do not provide unbiased and reliable estimates, thus one has to resort to the cointegration techniques: Johansen test, in case all the variables are non-stationary with the same order of integration, or the ADRL (Autoregressive Distributed Lag) in the case some variables are stationary and others non-stationary.

For the cointegration techniques, once it is confirmed that the series are cointegrated we can apply the Error correction models (ECM) and causality tests, such as the Granger causality tests (Shrestha and Bhatta, 2018).

In our study, all the relevant variables (economic growth, research output, human capital, structural change) depict a trend in levels (see Figures 1 to Figure 6). Thus, they are non-stationary. In this case, the conventional methods of estimation (OLS, VAR) can lead to spurious results (Shrestha and Bhatta, 2018). Thus, we must resort to cointegration techniques. In case that there are one or more time-series that are cointegrated, we then can apply the Granger causality test to assess whether the relevant variables present unidirectional, bi-directional or no causality.

The following equation captures the reduced form of the relationship between the variables under analysis:

$$Y_t = \beta_1 + \beta_2 RO_t + \beta_3 HC_t + \beta_4 SC_t + \beta_5 (RO * HC)_t + \beta_6 (\mathrm{RO} * SC)_t + u_t \qquad (1)$$

Where t represents time and

Y - Proxy for economic growth

RO - Proxy for research output

HC – Proxy for human capital

SC - Proxy for structural change

u - Random perturbation term.

The econometric specification in (1) is estimated for global output and each scientific area (Physical sciences, Engineering & Technology, Life sciences, Social sciences, Clinical, Pre-clinical & Health Sciences, and Arts & Humanities).

3.2. Proxies for the relevant variables and main data sources

In this study, we assess for the Portuguese economy in the period from 1980 to 2019 the eventual long-term relation (cointegration) and causality between research output (global and by scientific areas) and economic growth, mediated by human capital and structural change.

The variable proxy for economic growth is often expressed both in levels (the GDP per capita) and in growth rates (the GDP per capita annual growth rate). Given that the level of GDP per capita is more adequate to capture differences in welfare in long-run (Hall and Jones 1999), we opted for levels instead of growth rates. It is important to refer that several studies related to research output-economic growth (e.g., Vinkler 2008, Jin 2010, Jaffe et al. 2013, Odhiambo and Ntenga 2016 see Vinkler 2008, Jin 2010, Jaffe et al. 2013, Odhiambo and Ntenga 2016) and empirical studies based on the neoclassic theory have used the GDP (per capita) in levels (see Barro and Sala-i-Martin, 1997). We gathered the real GDP per capita (constant prices 2016, €) from Pordata.[4] Figure 1 depicts the time series of the Portuguese real GDP per capita from 1980 to 2019. It is observed an upward trend between 1980 to 2019. In 2019, the Portuguese GDP per capita was 19731 euros, more than double that of 1980, which was 9463 euros and on average each Portuguese have 15179 euros.

Since 2003, worsened with the Great Recession after 2008, Portugal observed a substantial decrease in the growth and even decrease (from 2008 until 2013) of its GDP per capita, in part explained by the strong restrictive (monetary, income and fiscal) policies undertook in Troika's period (2011-2014). After 2015, Portugal observed a recovering of its standard of living.

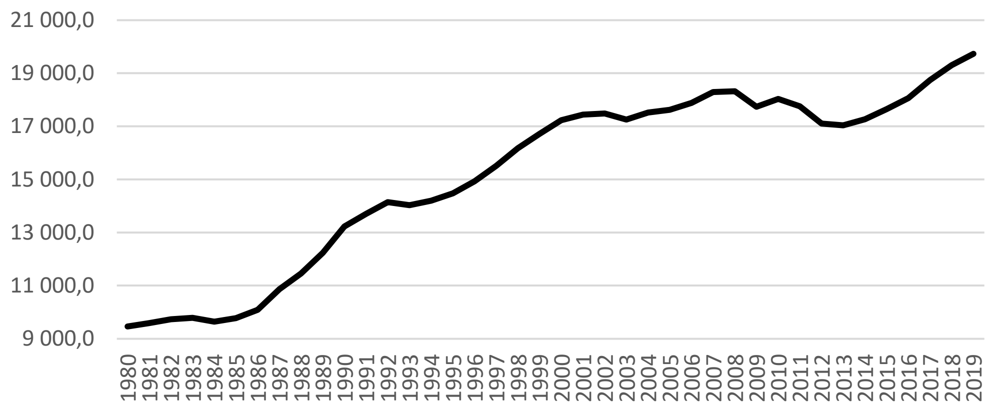

Figure 1: Evolution of the Portuguese real GDP per capita (constant prices 2016, €)
Source: Pordata

The measurement of research output is not a simple task (Inglesi and Pouris, 2013), two main proxies have been proposed: patents and research publications (Inglesi-Lotz, Hakimi and Pouris 2018). There are several drawbacks that advice against the use of patents as a proxy for research output. Firstly, even in highly advanced countries, patents are a very small part

[4] In https://www.pordata.pt/Portugal/PIB+e+PIB+per+capita+a+pre%c3%a7os+constantes+(base+2016)-2953, accessed December 2020.

of the outcome of the research activity (Inglesi-Lotz and Pouris 2013, Lee et al. 2011). Secondly, far from the technological frontier countries' innovative and research activities seldom involve patents given the productive specialization of such countries (mainly based on low or medium low technology-based industries) and the embryonic stage of intellectual property rights institutions (Yasgul and Guris, 2016).

There are alternative metrics to measure research publications: number of articles published (e.g., Jin, 2009; Lee et al., 2011; Solarin and Yen, 2016), the ratio of the total number of scientific publications in a given country to the total number of scientific publications in the world (Inglesi- Lotz et al., 2014; Inglesi-Lotz et al., 2015), and the number of citations or High Quality Science Index (HQSI) (Allik, 2013, Allik et al. 2020), which attempt to reflect the relative quality of the publications (King 2004; Vinkler 2008).

Given that we seek to explore the impact of research output on economic growth, our main focus is on how the quantity of publications is likely to impact on country's economic growth. Moreover, as we are analyzing only the Portuguese case, we opted to consider the number of Portuguese scientific publications without relativizing it to the total number of scientific publications in the world but relativizing it to the total population. Similar options were taken by studies in this area (e.g., Jin, 2009; Lee et al., 2011; Solarin and Yen, 2016). We gathered the research output data from the InCites dataset from Web of Science. We selected the articles by research area - from capital good (Physical sciences, Engineering & Technology, Life sciences, Social sciences) to final good (Clinical, Pre-clinical & Health Sciences, and Arts & Humanities) - using the GIPP scheme, in sources indexed in the Web of Science per 1000 inhabitants for the period from 1980 to 2019. Figure 2 depicts the evolution of research output. The number of publications per 1000 inhabitants increased over the period in analyses, the global research output in global terms in 2019 is near to 2 publications per 1000 inhabitants, is around 100 times the number of publications per 1000 inhabitants in 1980 with 0.02. In 1980 the research output was residual compared to what is producing nowadays. In 2019, the scientific area with more publication is the Life Science with 0.67 publication per 1000 inhabitants followed by Physical Science (0.51) and Engineering & Technology (0.50), Clinical and Pre-Clinical & Health (0.41), Social Sciences (0.32) and Arts and Humanities (0.07). On average each 1000 inhabitants produces 0.55 article.

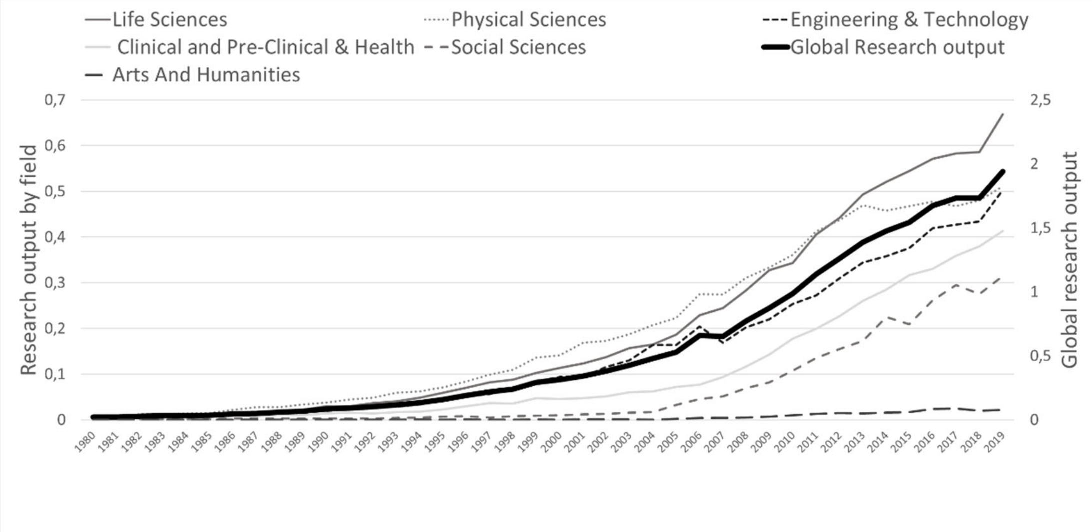

Figure 2: Research output (number of publications per 1000 inhabitants) globally and by areas of research, Portugal, 1980-2019

Source: Own elaboration based on data from InCites dataset (Web of Science).

Regarding the proxy for human capital stock, there are different alternatives in literature, namely literacy rates, school enrollment ratios, and average years of schooling, to mention the most used. The literacy rates omit significant elements of human capital, such as "numeracy, logical and analytical reasoning and scientific and technological knowledge" taking only in consideration the elementary level (Le, Gibson and Oxley, 2005, 18). The school enrollment ratios just take in consideration the number of students that are registered at a specific level of education, thus reflecting the future and not the present human capital stock (Benos and Zotou, 2014; Le, Gibson and Oxley, 2005). The average years of schooling allows to quantify the accumulated investment in education and the total amount of the formal education attained, being therefore considered a reasonable proxy for human capital stock (Bassetti, 2007, Benos and Zotou, 2014).

Specifically, we use the average years of schooling of the adult population (individuals aged 25 or more) in line with other relevant studies (e.g., Moral-Benito 2012; Bodman and Le 2013; Teixeira and Queirós 2016). The data comes from United Nations Development Programme (2019) data, encompassing the period from 1990 to 2019 combined with data from de La Fuente and Domenech (2002) that comprising the period from 1980 to 1990.[5]

According to Figure 3, in 1980 one adult Portuguese citizen possessed, on average, around 5.8 years of formal schooling. In the period of analysis, that figure increased reaching 9.3 years of formal schooling in 2019. Each Portuguese with more than 25-year-old hold on average 7 years of schooling.

[5] Data from United Nations Development Programme (2019) from http://hdr.undp.org/en/indicators/103006, last accessed December 2020.

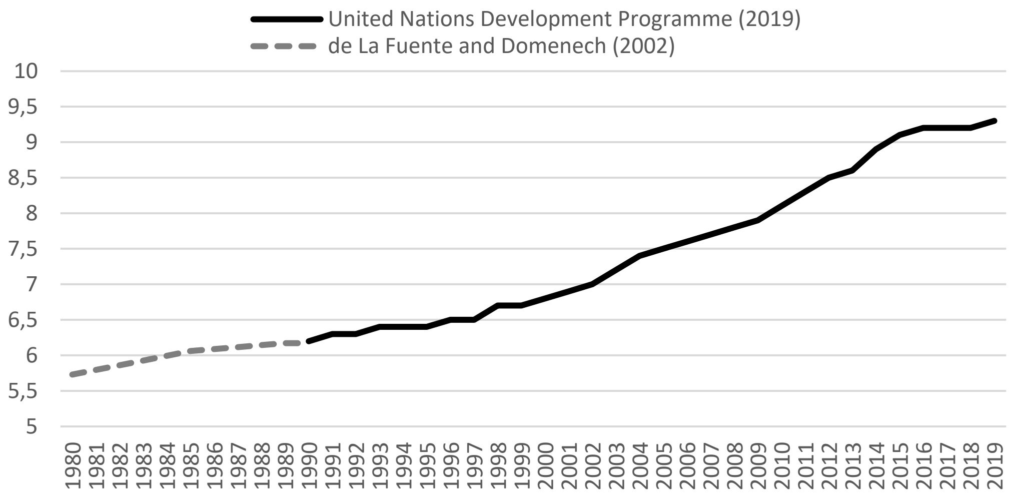

Figure 3: Human capital stock, Portugal, 1980-2019
Source: Own elaboration based on United Nations Development Programme (2019) and de La Fuente and Domenech (2002)

Concerning that structural change is defined as the evolution, over a period of time, of the weight, in terms of employment, production or value-added, of a given sector (e.g., primary, secondary, tertiary) (Teixeira and Queirós, 2016). In the present study, we considered the weight of industry in total production (Figure 4). The data combines information from Banco de Portugal(1980 to 1995) and Pordata (1996 to 2019).

During the period of 40 years, between 1980 to 2019, Portugal experienced a considerable change in its economic structure with weight of the industrial product in total product from 28% down to 17.5%. The evolution, however, was not linear. From 1988 until 2009 the share of the industry fell considerably, reaching its lowest value (12.6%), increasing thereafter reaching 17.5% in 2019.

Figure 4: Structural change (weight of the industrial product in total product), Portugal, 1980-2019

Source: 1980-1995 - Banco de Portugal, Séries Longas do BdP; 1996-2019 - Pordata.

4. Empirical results

4.1. Unit root tests

The analyses start by assessing, by visual inspection and resorting to formal tests, most notably the Augmented Dickey-Fuller (ADF) and the Phillips-Perron tests, whether the variables are stationary or non-stationary, and in the latter case what is the order of integration (that is, how many times the variable must be differentiated to become stationary).

The visual inspection of the variables in levels and first differences (see Table A4 in Appendix) suggest that the variables in levels are non-stationary (i.e., have a trend), whereas in the first differences are stationary. This evidence is corroborated by the formal unit roots tests. The ADF tests if a variable follows a unit-root process, being the null hypothesis that the variable contains a unit root (i.e., is non-stationary) against the alternative that the variable was generated by a stationary process (Dickey and Fuller 1979). As demonstrated in Table 1, we cannot reject the null hypothesis that the variables in levels have a unit root, but we reject the null hypothesis that the variables in their first differences have a unit root. Similar results are obtained when we use the Phillips–Perron unit-root test.[6] Both tests confirm that all the variables in levels are non-stationary, i.e., the null hypothesis that there is one-unit root cannot be rejected considering the variables in levels, whereas in their first differences the null hypothesis is rejected, that is, are stationary in the first differences. In a nutshell, according to ADF and Phillips-Perron tests, all the variables are integrated of order one, I(1). Thus, the series can be cointegrated (Dickey et al. 1991), in other words, there can be one or more stationary linear combinations of the series, pointing a stable long-run relationship between them.

[6] The null hypothesis of the Phillips–Perron unit-root test is that the variable contains a unit root against the alternative is that the variable was generated by a stationary process (Phillips and Perron, 1988). This test uses Newey–West (1987) standard errors to account for serial correlation, whereas the augmented Dickey–Fuller test uses additional lags of the first-differenced variable.

Table 1: Unit root tests

		Augmented Dickey–Fuller (p-value)		Phillips-Perron (p-value)	
		Levels	1st differences	Levels	1st differences
Economic growth	GDP per capita	-0.787 (0.9667)	-2.831* (0.0540)	-1.187 (0.9132)	-2.921** (0.0429)
Research output	Global	-0.075 (0.9934)	-6.521*** (0.0000)	0.552 (0.9969)	-6.516*** (0.0000)
	Life sciences	-0.270 (0.9902)	-6.346*** (0.0000)	-0.431 (0.9859)	-6.386*** (0.0000)
	Physical Sciences	-0.229 (0.9910)	-5.478 *** (0.0000)	0.469 (0.9968)	-5.495*** (0.0000)
	Engineering Technology	-2.916 (0.1571)	-5.441*** (0.0000)	-3.070 (0.1134)	-5.444*** (0.0000)
	Social Sciences	-2.611 (0.2748)	-7.488*** (0.0000)	-2.540 (0.3084)	-7.791*** (0.0000)
	Clinical Pre- Clinical Health	-3.861 (0.0137)	-13.188*** (0.0000)	-3.933 (0.0109)	-12.061*** (0.0000)
	Arts and Humanities	-0.737 (0.8369)	-10.446 *** (0.0000)	-0.257 (0.9314)	-11.397*** (0.0000)
	Human capital	-1.307 (0.8862)	-5.064*** (0.0000)	-1.386 (0.8651)	-5.208**** (0.000)
	Structural change	-0.867 (0.9596)	-5.258*** (0.0000)	-1.039 (0.9386)	-5.220**** (0.000)
Interaction between human capital and research output	Global	-1.556 (0.8093)	-7.641*** (0.0000)	-1.579 (0.8005)	-7.569*** (0.0000)
	Life sciences	-1.275 (0.8940)	-6.837*** (0.0000)	-1.550 (0.8114)	-6.806*** (0.0000)
	Physical Sciences	-1.728 (0.7382)	-4.440*** (0.0003)	-1.694 (0.7537)	-4.632*** (0.0001)
	Engineering Technology	-2.929 (0.1531)	-6.211*** (0.0000)	-3.041 (0.1210)	-6.290*** (0.0000)
	Social Sciences	-2.395 (0.3822)	-7.276 *** (0.0000)	-2.290 (0.4396)	-7.506 *** (0.0000)
	Clinical Pre- Clinical Health	0.022 (0.9604)	-12.112 *** (0.0000)	-3.043 (0.1204)	-10.904*** (0.0000)
	Arts and Humanities	-0.926[1] (0.7794)	-10.311*** (0.0000)	-0.481[1] (0.8957)	-11.358 *** (0.0000)
Interaction between structural change and research output	Global	-2.522 (0.3171)	-6.616 *** (0.0000)	-2.831 (0.1859)	-6.600*** (0.0000)
	Life sciences	-3.025 (0.1253)	-6.255*** (0.0000)	0.391 (0.9812)	-6.284*** (0.0000)
	Physical Sciences	-1.816 (0.6970)	-6.078*** (0.0000)	-2.079 (0.5579)	-6.079*** (0.0000)
	Engineering Technology	-3.051 (0.1184)	-6.939 *** (0.0000)	-2.941 (0.1494)	-6.925*** (0.0000)
	Social Sciences	-1.512 (0.8252)	-6.043 *** (0.0000)	-1.611 (0.7880)	-6.044*** (0.0000)
	Clinical Pre- Clinical Health	-1.641 (0.7760)	-8.127*** (0.0000)	-1.555 (0.8096)	-7.886*** (0.0000)
	Arts and Humanities	-2.957 (0.1444)	-9.288*** (0.0000)	-3.055 (0.1174)	-9.648*** (0.0000)

Notes: ***, **, *, statistically significant respectively at 1% , 5%, 10%; The proxies for economic growth, research output and human capital are in logarithm.

Source: Own computation using Stata 16.1.

4.2. Johansen cointegration test and long-run relationships

In this study it is assessed whether a the long-run relationship between research output (global and by scientific area - Physical sciences, Engineering & Technology, Life sciences, Social sciences, Clinical, Pre-clinical & Health Sciences, and Arts & Humanities), human capital and structural change interacted with research output and economic growth exists.[7] For obtaining the estimations we resort to the software Stata 16.1. The unit root tests (Section 4.1) show that all the relevant variables are integrated of the same order, I (1). Thus, we can proceed testing whether the long run cointegration relationships exist between the variables using the Johansen cointegration test (Johansen and Juselius 1990).

To uncover the number of cointegration vectors, we apply the trace test which tests the null hypothesis of *r* cointegrating vectors against the alternative hypothesis of *n* cointegrating vectors. The Trace test generally rejects the null hypothesis that economic growth, research output, and the interaction variables between research output and human capital/ structural change have no cointegrating relationship (that is, the null hypothesis of the number of linearly independent cointegrating relationships (*r*) is 0) at the 5% level (see Table 2). Indeed, the Trace test strongly rejects the null hypothesis of no cointegration (r = 0) in all the models and fails to reject the null hypothesis of at most four (Physical Sciences, Social Sciences and Arts & Humanities) or five (Global RO, Life Sciences, Engineering Technology, Clinical Pre- Clinical Health) cointegrating equations (r = 4 or 5). Thus, we accept the null hypothesis that there is 4 or 5 cointegrating equations in the multivariate models.

[7] In Annex, Tables A5-A7, we present the estimations for the long-run relationship considering economic growth proxied by the annual growth rate of the real GDP per capita instead of the level of real GDP per capita. The results obtained do not differ substantially from the ones estimated using the real GDP per capita. Thus, our results regarding the main variables are robust.

Table 2: Johansen cointegration Trace test – the number of cointegration vectors

		None	At least 1	At least 2	At least 3	At least 4	At least 5
Global RO	**Trace statistic**	267.85**	165.74**	103.38**	59.34**	28.57**	3.58
	5% critical value	104.94	77.74	54.64	34.55	18.17	3.74
Life sciences	**Trace statistic**	245.29**	142.69**	85.33**	49.55**	24.73**	2.07
	5% critical value	94.15	68.52	47.21	29.68	15.41	3.76
Physical Sciences	**Trace statistic**	279.95**	195.19**	113.12**	52.74**	11.46	
	5% critical value	94.15	68.52	47.21	29.68	15.41	
Engineering Technology	**Trace statistic**	227.82**	155.49**	100.22**	51.63**	27.36**	6.70
	5% critical value	82.49	59.46	39.89	24.31	12.53	3.84
Social Sciences	**Trace statistic**	244.78**	138.82**	78.98**	41.88**	7.44	
	5% critical value	94.15	68.52	47.21	29.68	15.41	
Clinical Pre-Clinical Health	**Trace statistic**	224.45**	135.14**	76.32**	32.51**	15.84**	4.84
	5% critical value	82.49	59.46	39.89	24.31	12.53	3.84
Arts & Humanities	**Trace statistic**	165.64**	111.21**	67.14**	30.32**	11.66	
	5% critical value	82.49	59.46	39.89	24.31	12.53	

Notes: Trace test is a Johansen cointegration test for the null hypothesis that, among GDP per capita (ln) and Research Output (RO) (ln) plus Human Capital (HC) (ln), Structural Change (SC), and RO interacted with HC and SC, there are *r* linearly independent cointegration relations, that is, the 5 variables share 5-*r* stochastic tendencies; ** represents the rejection of the null hypothesis that among the 5 variables there are *r* linearly independent cointegration relations (compared to the alternative that there are *r*+1 linearly independent cointegration relations) with a 5% statistical significance.
Source: Own computation using Stata 16.1.

As we do not have an underlying solid theoretical reasoning for imposing restrictions on the parameters of the long-run relationships, we opted for the Johansen normalization procedure which restricts the coefficient on economic growth to a unit. Table 3 presents the estimated long-run relationships (the Vector Error Correction Model – VECM) between Economic growth (EG - GDP per capita) and Research Output (RO) plus Human Capital (HC), Structural Change (SC), and RO interacted with HC and SC on this restriction.

Post-estimation specifications testing indicates that the vector error-correction models (VECM) associated with the cointegration relationships are well specified. Specifically, the overall Jarque-Bera statistics do not reject (at 5% significance) the null hypothesis that the disturbances in the VECM are normally distributed. Moreover, we cannot reject the null hypothesis that there is no (second order) autocorrelation in the residuals (according to the Lagrange multiplier test), and the eigenvalue stability condition showed that estimated cointegration equations are well specified (the estimated roots are not close to 1), that is, they are stationary as required.

The results evidence that in the long run, the relation between Global research output (number of publications per 1000 inhabitants) and economic growth (GDP per capita) is positive and significant at 1% level. An increase of 1% of global research output is associated with 0.541% increase in economic growth. Portugal has been internationally recognized by the evolution of the scientific production in the last 30 years (OECD, 2019b). That is, in the last 40 years (1980-2019), increases of the global research output are associated with increases in the Portuguese GDP per capita (see Table 3). These results are aligned with the theoretical expectations that scientific knowledge and economic growth evolve jointly (De Moya-Anegón and Herrero-Solana 1999; Solarin and Yen 2016).

We further found that in the long run, the relation between hard sciences research output and economic growth is positive and significant at 1% level. In contrast, the results regarding the relationship between the soft sciences and the economic growth suggest a negative and significant relationship at 1% level, for both Clinical Pre- Clinical Health and Arts and Humanities. These results are partially in line with those by Antonelli and Fassio (2016), who explore the contribution of the diverse areas of research on economic growth from hard sciences to soft science and conclude that hard science contribute more to total factor productivity (TFP). They, however, do not find a negative relation in any of the areas of research output and economic growth.

Excluding in the model related to the global output, when significant (i.e., in the models of Engineering Technology, Social Sciences, Clinical Pre- Clinical Health and Arts and Humanities), human capital emerges, in the long run, positively associated with economic growth. An economy characterized by high levels of human capital (education/ training) tends to be more productive and innovative, leveraging economic growth (Mankiw et al., 1992; Wößmann, 2003; Bodman and Le, 2013). We further found that, with exception of the soft sciences (Clinical Pre- Clinical Health and Arts and Humanities), the long-run relationship between human capital as a mediator of research output and economic growth is statistically significant and negative. This suggests that for Portugal, between 1980 and 2019, increases in the years of schooling mitigated the positive association of research output and the real GDP per capita.

Regarding the association of structural change and economic growth, it was found to be positive and significant for Life Sciences, Engineering Technology and Social Sciences. Many countries since the 1950s and 1960s increased their living standards by reallocating resources from agriculture in the direction of higher-productivity sectors, namely the industrial and services sectors (Gabardo et al. 2017). Those shifts led to a positive structural change that boosted productivity and, consequently, sustained economic growth paths (Martins, 2019).

Moreover, we found that, except for Arts and Humanities, there is a positive and significant long-term correlation between the interaction of structural change and research output and economic growth. In other words, in the long run, structural change tends to amplify the positive association of research output and economic growth.

Table 3: Long-term relations of Economic Growth and Research Output, Portugal, 1980-2019

		Hard sciences				Soft Sciences	
	Global RO	**Life sciences RO**	**Physical Sciences RO**	**Engineering Technology RO**	**Social Sciences RO**	**Clinical Pre-Clinical Health RO**	**Arts and Humanities RO**
Research Output (RO)	**0.541***** **(0.065)**	**1.489***** **(0.102)**	**0.673***** **(0.066)**	**1.685***** **(0.694)**	**0.768***** **(0.070)**	**-2.947***** **(0.292)**	**-1.887***** **(0.358)**
Human capital (HC)	**-0.364**** **(0.162)**	0.102 (0.190)	0.397 (0.452)	**4.484***** **(0.155)**	**0.476**** **(0.208)**	**3.268***** **(0.271)**	**3.835***** **(0.751)**
RO*HC	**-0.119***** **(0.040)**	**-0.647***** **(0.072)**	-0.029 (0.111)	-0.333 (0.408)	**-0.178***** **(0.058)**	**2.035***** **(0.190)**	**1.158***** **(0.295)**
Structural change (SC)	**-0.610***** **(0.048)**	**0.413***** **(0.070)**	0.043 (0.172)	**0.890***** **(0.219)**	**0.862***** **(0.119)**	**-1.463***** **(0.365)**	-0.890 (0.901)
RO*SC	**0.162***** **(0.028)**	**0.105**** **(0.047)**	**0.474***** **(0.063)**	**1.190***** **(0.066)**	**0.275***** **(0.027)**	**0.775***** **(0.098)**	0.243 (0.157)
Lags	4	3	4	4	3	4	4
VECM specification	Constant	Constant	Constant	None	Constant	None	None
No. of cointegrating vectors	5	5	4	5	4	5	4
Jarque-Bera test (overall) (1)	6.144 (0.909)	10.870 (0.090)	13.509 (0.333)	15.878 (0.197)	20.395 (0.060)	12.919 (0.375)	12.732 (0.389)
Lagrange multiplier test (2) — Lag 1	0.990	0.667	0.235	0.590	0.391	0.188	0.014
Lagrange multiplier test (2) — Lag 2	0.739	0.277	0.945	0.498	0.383	0.245	0.654
Eigenvalue stability condition (3)	0.639	0.216	0.306	0.031	0.075	0.236	0.239

Note: Structural change - weight of industry product in total GDP. All variables are in logarithm; The number of lags was established according to the Schwarz's Bayesian information criterion (SIC); (1) H0: the disturbances in the VECM are normally distributed; (2) H0: no autocorrelation at lag order; (3) the cointegrating equations are stationary when the estimated root is not close to 1.

Source: Own computation using Stata 16.1

4.3. Granger (non-)causality test

When two or more time-series are cointegrated, then there must be (Granger) causality between them, either one-way or in both directions (Granger 1988). In the previous section we have confirmed, resorting to the Johansen method, the existence of at least one cointegration relationship between Economic growth (EG), Research Output (RO), Human Capital (HC), Structural Change (SC), and RO interacted with HC and SC. Thus, we proceed testing for Granger (non-)causality.

Considering the case of our core time series, Economic growth (EG) and Research Output (RO), RO is said to Granger-cause EG if the latter can be better predicted using the histories of both RO and EG. In this context, we can test for the absence of Granger causality by estimating the vector autoregressive models (VAR). Table 4 presents the results of the Granger (non-)causality test for both the relevant models.

Results demonstrate that in the short run there is a positive causality running from global research output to economic growth as the null hypothesis of Granger causality from global research output to economic growth is rejected at 1% level of significance (see Table 4). We thus conclude that between 1980 and 2019, increases in global research output strongly foster improvements in real GDP per capita (economic growth). Therefore, H1 (*At the country level, the overall research output tends to positively impact on economic growth*) is validated. Such results unambiguously demonstrate the critical relevance of research output production to the Portuguese economic growth in the last forty years. The findings are in line with some earlier empirical studies that have been identified causality running from research output to economic growth for several countries and periods: Australia, Austria, Germany, India, and The Netherlands from 1981 to 2007 (Lee et al. 2011); the US, from 1981 to 2011 (Inglesi-Lotz et al. 2014; Ntuli et al. 2015); and Finland, Hungary, and Mexico (Ntuli et al. 2015).

The evidence for Portugal in the last forty years fits theoretical fundamentals according to which a higher level of knowledge, produced through research activity, promotes economic growth by the development of innovation, that lead to improvements of productive capacity and labour quality (Hatemi-J et al. 2016; Ntuli et al. 2015). It also agrees with disparate evidence and accounts of other studies focusing on Portugal's economic growth. For instance, the increase of the R&D intensity was extremely important to the economic growth process in Portugal during that period of 1960 to 2001 (Teixeira and Fortuna, 2004).

Analyzing the relationship between research output by areas and economic growth, the results of Granger causality suggest that the research output of both 'hard sciences' and 'soft sciences' positively impacts on economic growth. Moreover, the impact is strong for both 'hard sciences' and 'soft sciences'. As such, our data do not corroborate H1a (*The impact of research output on economic growth is likely to be higher in fields of science where knowledge is similar to a capital good, 'hard sciences', than in fields of science where it resembles a final good, 'soft sciences'*).

These results are thus not completely aligned with Antonelli and Fassio's (2016) findings. These authors, exploring the period of 1998–2008 in 13 countries, concluded that knowledge associated to hard and soft sciences conducts to different effects on economic growth. Specifically, they uncovered that hard sciences, which produce knowledge with high level scope of application and appropriation can, to a larger extent than soft sciences (which produce knowledge with a smaller scope of application and appropriation, conducting increases in final consumer utility), promote technological change and generate economic growth.

The interaction between human capital and research output (global and by areas) impacts significantly (Granger causes) but negatively on economic growth. This suggests that high levels of human capital mitigate the positive impact of research output (global and by areas) on economic growth. Consequently, H2 (*High levels of human capital enhance the impact of research output (global and field related) on economic growth*) is rejected by our data. Such results evidence important mismatches between the formal education and the scientific production in Portugal. The observed increase in terms of the average number years of formal schooling does not seem to be aligned with the Portuguese research output in terms of their joint impact on economic growth.

Table 4: Short-run Granger (non-) causality test

The null hypothesis	Global RO	Hard Sciences				Soft Sciences	
		Life sciences RO	**Physical Sciences RO**	**Engineering Technology RO**	**Social Sciences RO**	**Clinical Pre-Clinical Health RO**	**Arts and Humanities RO**
Research Output (RO) *does not* Granger cause Economic growth (EG)	**1.537***** **(0.165)**	**1.919***** **(0.197)**	**0.440***** **(0.064)**	**0.776***** **(0.254)**	**1.056***** **(0.147)**	**1.459***** **(0.247)**	**0.569***** **(0.152)**
Human capital (HC) *does not* Granger cause EG	-0.127 (0.348)	**-0.716**** **(0.316)**	**1.186***** **(0.333)**	-0.355 (0.261)	-0.211 (0.295)	-0.466 (0.401)	-0.089 (0.346)
The interaction between RO and HC *does not* Granger cause EG	**-0.624***** **(0.094)**	**-0.881***** **(0.102)**	**-0.720***** **(0.104)**	**-0.319**** **(0.153)**	**-0.425***** **(0.080)**	**-0.652***** **(0.130)**	**-0.289***** **(0.103)**
Structural Change (SC) *does not* Granger cause EG	**0.557***** **(0.062)**	**0.652***** **(0.098)**	**0.535***** **(0.081)**	**0.465***** **(0.126)**	**1.030***** **(0.161)**	**0.902***** **(0.185)**	**0.634**** **(0.253)**
The interaction between RO and SC *does not* Granger cause EG	**0.116***** **(0.045)**	0.069 (0.047)	**0.087**** **(0.042)**	0.048 (0.053)	**0.139***** **(0.043)**	**0.109***** **(0.063)**	0.023 (0.051)
EG *does not* Granger cause RO	0.083 (0.254)	0.247 (0.367)	**-0.630*** **(0.339)**	**1.458***** **(0.411)**	-0.305 (0.713)	**1.215**** **(0.482)**	-0.192 (0.923)
EG *does not* Granger cause HC	-0.011 (0.054)	-0.020 (0.061)	0.049 (0.044)	0.050 (0.049)	**0.810*** **(0.048)**	0.062 (0.045)	**0.069**** **(0.035)**
EG *does not* Granger cause SC	**-0.803***** **(0.278)**	**-0.717**** **(0.310)**	**-0.724***** **(0.280)**	**-0.769***** **(0.211)**	**-0.524***** **(0.188)**	**-0.595***** **(0.193)**	**-0.609***** **(0.129)**
RO *does not* Granger cause HC	**-0.241***** **(0.065)**	**-0.156**** **(0.075)**	**-0.042*** **(0.023)**	**-0.294***** **(0.098)**	**-0.097*** **(0.056)**	-0.104 (0.077)	**-0.078*** **(0.046)**
HC *does not* Granger cause RO	1.003 (0.645)	-0.018 (0.715)	**2.485***** **(0.921)**	1.177 (0.847)	**7.124***** **(1.709)**	**4.845***** **(1.333)**	**5.164***** **(2.777)**
RO *does not* Granger cause SC	-0.338 (0.335)	-0.386 (0.376)	0.014 (0.146)	0.393 (0.422)	**-0.438**** **(0.222)**	**-0.549*** **(0.329)**	**-0.337**** **(0.169)**
SC *does not* Granger cause RO	**-0.271**** **(0.116)**	**-0.383*** **(0.222)**	-0.342 (0.224)	-0.335 (0.409)	**-2.499***** **(0.935)**	-0.714 (0.615)	**-6.311***** **(2.026)**

Note: Structural change - weight of industry product in total GDP. *** (**) [*] statistically significant at 1% (5%) [10%]; the estimates of VAR coefficients are displayed with standard errors in brackets.
Source: Own computation using Stata 16.1.

Structural change unambiguously and positively (Granger) causes Portuguese economic growth in the last forty years. Moreover, and mostly important, high levels of structural change towards industry production significantly leverage the impact of global and physical sciences, social sciences and clinical pre- clinical health (but not life sciences, engineering technology, and arts and humanities) research output on economic growth as the interaction term between structural change and that research outputs (Granger) cause economic growth. In this vein, H3 *(Structural change towards industries can boost the impact of research output (global and field related) on economic growth)* is partially validated. These results are in line with Pena-Vinces et al.'s (2019) findings. The authors analyzed South American economies between

2003–2013 and concluded that scientific capacity and manufacturing development had a larger combined effect on international competitiveness than their individual marginal effects.

5. Conclusion

New knowledge can be created by scientific research (Inglesi-Lotz and Pouris 2013) and increase economic growth performance of countries (Solarin and Yen 2016). Therefore, understanding the effect of research activity on economic growth constitutes a crucial and useful endeavor. Moreover, albeit recognizing that all areas of research are important and can provide benefits to the society (Sutherland et al. 2011) that go beyond the effect they may have in terms of economic growth (Antonelli and Fassio 2016), assessing whether (global and by areas) research output impact on economic growth and is aligned with countries' human capital and structural change is fundamental for both scientific and policy spheres.

Despite the late awakening (Malheiros, 1992), Portugal has noticed significative dynamic in terms of research output over the last forty years (MCTES, 2017). Notwithstanding, it remains a laggard country, characterized by considerable a backwardness regarding technology and innovation performance (Alves, 2017; Santos, 2019), and the impact of the evolution of human capital and structural change on the country's productivity dynamics and growth process has been debatable (Pereira and Lains, 2012; Alves, 2017).

Based on time-series analyses for Portugal from 1980 to 2019 and resorting to cointegration and Granger causality analyses, this study assesses the role of research output in the economic growth performance of the country and scrutinizes whether structural change processes towards industry and human capital stock amplify or mitigate the direct impact of research output (global and by areas) on economic growth.

The study contributes to literature at three main levels: theoretical, methodological, and empirical. At the theoretical level, the study explores and adapt, in a novel perspective, the contribution by Antonelli and Fassio (2016), considering research output areas in two groups of knowledge, hard (life sciences, physical sciences, engineering and technology, and social sciences) and soft sciences (clinical, pre-clinical and health sciences, and arts and humanities). The former is characterized by knowledge as a capital good whereas the latter is characterized by knowledge as a final good. At the methodological level, the study contributes to the scanty literature resorting to time series analyses considering direct and indirect (interaction) effects of (global and by areas) research output and economic growth via human capital and structural change. At the empirical level, the current study offers new and challenging evidence of the long and short run effects of research output on economic growth in a technological laggard country.

The results of this study unambiguously underline the important role of research output in fostering the economic growth of Portugal. Specifically, global, hard, and soft sciences research output significantly promotes economic growth in the short and (in the case of global and hard sciences) long-run. Additionally, structural change towards the industry emerged as a mediator factor significantly amplifying the positive impact of the research output on economic growth. In contrast, high levels of human capital mitigate the impact of research output on economic growth evidencing the existence of human capital-research output mismatches.

These results have important policy implications. First, they suggest that to achieve higher economic growth is essential for Portugal to invest in science, regardless of the scientific domain. Secondly, directing the policy incentives towards fostering a strong industrial basis is likely to enhance economic growth effects derived from investments in science/ research output. Thus, public policies should direct specific instruments and programs which promote the relationship between science and industry. Thirdly, it is essential to overcome the mismatch between human capital and research output, which can be achieved by improving the dialogue between education, science and industry, seeking to design education and formation offers closer to the industry needs, stimulating the effective integration of the PhD holders into companies and the mobility of researchers between industry and academia (OECD, 2008; Vieira and Fiolhais, 2015; OCDE, 2019). Finally, it is urgent to improve existing and/or implement new efficient mechanisms of transferring knowledge developed in Universities and Research Labs to the industry and marketplace (Gibson and Naquin, 2011). In this latter dimension, the noticeable expansion of technological infrastructures (TTOs, Business Incubators, Science Parks) observed in the last twenty years in Portugal (Ratinho and Henriques, 2010; Arqué-Castells et al., 2016; Cartaxo and Godinho, 2017) needs to be followed by an effective improvement in their efficiency levels in term of technology transfer is significant growth effects are to be required (Teixeira and Monteiro, 2018).

Although this study conveys some novel contributions, it nevertheless entails limitations that are likely to constitute challenging avenues for further and future research. First, it would be interesting besides assessing the impact of the quantity of research output (number of publications) to adjust for the quality of that research output by, for instance, including citations and related indicators. Secondly, it is important to consider the heterogeneity of human capital by including not only the aggregate number of schooling years but also the stock of human capital in secondary and tertiary education and/ or by courses which would enable to further elaborate on the human capital mismatches founded.

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Annex

Table A1: A selection of studies that focused on Portuguese economic growth (at the national, regional, and set of countries levels)

Type of analyse	Countries	Determinant of economic growth	Authors	EG measurement	Variable	Proxy	Method	Period	Result
National	Portugal	Science, technology and innovation	Teixeira and Fortuna (2004)	Growth of total factor productivity	R&D	Total accumulated expenditure on R&D	Cointegration	1960–2001	+
		Human capital and skills	Teixeira and Fortuna (2004)	Growth of total factor productivity	Human capital	Average years of schooling	Cointegration	1960–2001	+
			Pina and St Aubyn (2005)	GDP	Human capital	Average years of schooling	Vector autoregression (VAR)	1960–2001	+
			Pereira and St Aubyn (2009)	GDP	Human capital	Primary	Cointegration VAR and Granger causality	1960-2001	<-> EG
						Secondary			
						Tertiary			
			Santos, Domingos, Sousa and Aubyn (2018)	Gross value added (GVA)	Human capital	Skill-adjusted human labor	Cointegration and Granger causality tests	1960–2009	+
		International Trade and FDI	Oxley (1993)	GDP	Exports	Level of real exports	Cointegration and Granger causality tests	1865–1985	->EG
			Ramos (2001)	GDP	Exports	Real exports	Cointegration and Granger causality -VECM	1865-1998	<-> EG
					Imports	Real imports	Cointegration and Granger causality -VECM	1865-1998	<-> EG
			Andraz and Rodrigues (2010)	GDP	Exports	Real exports	Cointegration and Granger causality tests	1977-2004	Short-run: 0; Long-run: ->EG
					FDI	Real inward foreign direct investment	Cointegration and Granger causality tests	1977-2004	Short -run: <-> EG; Long run: -> EG

Type of analyse	Countries	Determinant of economic growth	Authors	EG measurement	Variable	Proxy	Method	Period	Result
			Shahbaz, Leitao, Uddin, Arouri and Teulon (2013)	GDP per capita	Trade openness	Real trade per capita (real exports + real imports)/population	ARDL-ECM, Granger causality	1980-2010	+
			Rebelo and Silva (2017)	Natural logarithm of labor productivity or employment	Exports variety	Evolve technology and innovativeness dimensions by using sectoral classification schemes	Cointegration	1967–2010	+
		Labor and demographic conditions	Shahbaz, Leitao, Uddin, Arouri and Teulon (2013)	GDP per capita	Employment	Labour force per capita	ARDL-ECM, Granger causality	1980-2010	->EG
			Morgado (2014)	GDP	Health	Life expectancy	Cointegration VAR and Granger causality	1960-2005	<- EG
					Health	Number of cases of infant mortality	Cointegration VAR and Granger causality	1960-2005	- <- EG
			Bento (2016)	GDP	Domestic tourists	Tourist arrivals of residents	Cointegration and Granger causality tests	1995-2015	->EG
					Foreign tourists	Tourist arrivals of non-residents	Cointegration and Granger causality tests	1995-2015	0
		Macroeconomic conditions	Rei (2007)	GDP per capita growth rate	Investment rate	Gross Fixed Capital Formation/GDP	Cointegration test, Granger causality	1960-2001	0
			Pereira and Pinho (2008)	GDP	Physical capital - public	Fixed capital formation of the public administrations by millions of euros in 1995 prices	Vector autoregression (VAR)	1976–2003	+
			Pereira and St Aubyn (2009)	GDP	Investment	Gross fixed capital formation	Cointegration VAR and Granger causality	1960-2001	+
			Marques, Fuinhas and Marques (2013)	GDP	Investment rate	Gross Fixed Capital Formation/GDP	Cointegration VAR and Granger causality -VECM	1993-2011	<-> EG
			Shahbaz, Leitao, Uddin, Arouri and Teulon (2013)	GDP per capita	Capital	Real capital per capita	ARDL-ECM, Granger causality	1980-2010	<- EG

Type of analyse	Countries	Determinant of economic growth	Authors	EG measurement	Variable	Proxy	Method	Period	Result
			Shahbaz, Benkraiem, Miloudi, and Lahiani (2017)	GDP per capita	Investment	Gross fixed capital formation	NARDL, Granger causality	1960-2015	+
			Santos, Domingos, Sousa and Aubyn (2018)	Gross value added (GVA)	Capital	Capital	Cointegration and Granger causality tests	1960–2009	+
		Institutions	Marques, Fuinhas and Marques (2013)	GDP	Domestic credit	Total domestic credit/GDP	Cointegration VAR and Granger causality -VECM	1993-2011	<- EG
					Stock market	Market capitalization/GDP	Cointegration VAR and Granger causality -VECM	1993-2011	<-> EG
			Shahbaz, Benkraiem, Miloudi, and Lahiani (2017)	GDP per capita	Financial development	Domestic credit to the private sector constant 2010 LCU	NARDL, Granger causality	1960-2015	+
			Bação, Gaspar and Simões (2019)	GDP per capita growth rate	Institutions	Corruption perceptions index	VAR	1980-2018	0
			Soares and Afonso (2019)	GDP per capita	Institutions	Unregistered economic activities resembles the ISTAT framework	Granger causality	1970–2015	<-> EG
		Natural Resources & Geographical	Shahbaz, Benkraiem, Miloudi, and Lahiani (2017)	GDP per capita	Energy	Electric power consumption (kWh)	NARDL, Granger causality	1960-2015	->EG
			Santos, Domingos, Sousa and Aubyn (2018)	Gross value added (GVA)	Energy	Primary energy consumption and useful exergy	Cointegration and Granger causality tests	1960–2009	+
Regional levels	thirty Portuguese NUTS3 regions	Science, technology and innovation	Simões, Andrade and Duarte (2013)	Real GDP per capita	Structural funds	ratio of structural funds received relative to GDP: manufacturing or services	Panel cointegration techniques	1995–2007	+
	Portugal, at the NUTS III level		Manso, Matos and Carvalho (2015)	Regional per capita GDP in constant 2006 prices	Culture: Number of publications	Number of periodicals per 1000 inhabitants	Fixed, random and pooled effects models	1999- 2010	+
	Portugal, at the NUTS III level				Technology: Number of landline phone	Number of landline phone accesses per 1000 inhabitants	Fixed, random and pooled effects models	1999- 2010	-

Type of analyse	Countries	Determinant of economic growth	Authors	EG measurement	Variable	Proxy	Method	Period	Result
	Portugal, at the NUTS III level	Human capital and skills	Manso, Matos and Carvalho (2015)	Regional per capita GDP in constant 2006 prices	Education	Number of Higher education establishments per 1000 inhabitants	Fixed, random and pooled effects models	1999- 2010	0
	Thirty Portuguese NUTS3 regions		Simões, Andrade and Duarte (2013)	Real GDP per capita	Human capital	average number of years of education of the workforce, total or relative to a certain schooling level	Panel cointegration techniques	1995–2007	-
	Portugal, at the NUTS III level	International trade and FDI	Manso, Matos and Carvalho (2015)	Regional per capita GDP in constant 2006 prices	International trade: exports and imports	Exports and imports by thousands of Euros per job	Fixed, random and pooled effects models	1999- 2010	0
	Portugal, at the NUTS III level	Labor and demographic conditions	Manso, Matos and Carvalho (2015)	Regional per capita GDP in constant 2006 prices	Labor market	primary employment; secondary employment; tertiary employment per 1000 inhabitants	Fixed, random and pooled effects models	1999- 2010	+
	Portugal, at the NUTS III level				Population: Aging index	Number of aging index	Fixed, random and pooled effects models	1999- 2010	-
	Portugal, at the NUTS III level				Population: Population density	number of inhabitants per km2	Fixed, random and pooled effects models	1999- 2010	-
	Portugal, at the NUTS III level				Population:Natural growth rate	percentage of natural growth rate	Fixed, random and pooled effects models	1999- 2010	0
	Portugal, at the NUTS III level				Population:Number of residents	resident population	Fixed, random and pooled effects models	1999- 2010	-
	Portugal, at the NUTS III level				Tourism	Number of accommodation capacity per 1000 inhabitants	Fixed, random and pooled effects models	1999- 2010	0
	Sub-regions of mainland Portugal	Macroeconomic conditions	Mota, Nunes and Matos (2010)	GNP per capita of each sub-region (NUT III)	Investment in building reconstruction	ratio of investment in reconstruction to the resident population in each sub-region of mainland Portugal	GMM system , LSDVC (Least Squares Dummy Variable Corrected)	1995-2006	+

Type of analyse	Countries	Determinant of economic growth	Authors	EG measurement	Variable	Proxy	Method	Period	Result
	Sub-regions of mainland Portugal			of mainland Portugal	Investment in new building	ratio of investment in new building to the resident population in each sub-region of mainland Portugal	GMM system , LSDVC (Least Squares Dummy Variable Corrected)	1995-2006	0
	thirty Portuguese NUTS3 regions		Simões, Andrade and Duarte (2013)	Real GDP per capita	Earnings inequality	average earnings of the employees working full time and the number of employees distributed according to the economic activity of firms	Panel cointegration techniques	1995–2007	-
	Portugal, at the NUTS III level		Manso, Matos and Carvalho (2015)	Regional per capita GDP in constant 2006 prices	Culture: Municipalities expenses in culture and sport	Municipalities expenses in culture and sport per 1000 inhabitants	Fixed, random and pooled effects models	1999- 2010	0
	Portugal, at the NUTS III level				Culture: Number of museums	Number of museums Number per 1000 inhabitants	Fixed, random and pooled effects models	1999- 2010	0
	Portugal, at the NUTS III level				Health: Hospitals e Health Centers	Hospitals e Health Centers per 1000 inhabitants	Fixed, random and pooled effects models	1999- 2010	0
	Portugal, at the NUTS III level				Health: Number of medical doctors	number of medical doctors per 1000 inhabitants	Fixed, random and pooled effects models	1999- 2010	-
	Portugal, at the NUTS III level				Public administration	Transfers from Central Administration Thousands of Euros per capita	Fixed, random and pooled effects models	1999- 2010	0
	Portugal, at the NUTS III level				Sectorial GVA/producivity	primary GVA per job; secondary GVA per job; tertiary per job	Fixed, random and pooled effects models	1999- 2010	-
	Portugal, at the NUTS III level				Social protection: Pensions paid by Social Security	Pensions paid by Social Security by thousands of Euros per capita	Fixed, random and pooled effects models	1999- 2010	0
	Portugal, at the NUTS III level	Institutions	Manso, Matos and Carvalho (2015)	Regional per capita GDP in	Justice	Criminality rate	Fixed, random and pooled effects models	1999- 2010	0

Type of analyse	Countries	Determinant of economic growth	Authors	EG measurement	Variable	Proxy	Method	Period	Result
				constant 2006 prices					
	Portugal, at the NUTS III level	Natural resources and geography	Manso, Matos and Carvalho (2015)	Regional per capita GDP in constant 2006 prices	Energy: Electricity consumption	consumption of electricity (in kWh) per capita	Fixed, random and pooled effects models	1999- 2010	+
Set of countries	**Portugal compares its composition with that of Spain, Greece and Ireland**	Science, technology and innovation	Amador and Coimbra (2007)	Average real GDP growth rate	Total Factor Productivity - TFP	Tecnological progress and efficiency	Stochastic Frontiers, Bayesian Methods.	1960- 2005	+
	Portuga and England		Lains (2008)	Labour productivity	Structural change	Dynamic effect - resources shift to sectors with productivity growth rates above the average	Dynamic shift-share analysis	1979-2002	-
	EU countries with na emphasis on Portugal		Santosa and Catalão-Lopes (2014)	GDP at 2005 prices	R&D	Research and Development (R&D) expenditure reference year 2000	Cointegration,Granger causality	1987-2008	0
	OECD countries	International trade and FDI	Dar and AmirKhalkhali (2002)	Annual growth rates of real GDP	exports	real exports	Random coefficients model	1971–1999	+
	24 OECD countries		Kónya (2006)	GDP at 1995 prices US dollars	Exports	exports of goods and services at 1995 prices US dollars	Granger causality	1960-1997	-
	OECD countries	Labor and demographic conditions	Dar and AmirKhalkhali (2002)	Annual growth rates of real GDP	Labor	Capitalization Ratio;Finance-Activity (FA),	Random coefficients model	1971–1999	0
	Portugal compares its composition with that of Spain, Greece and Ireland		Amador and Coimbra (2007)	Average real GDP growth rate	Labour	Employment	Stochastic Frontiers, Bayesian Methods.	1960- 2005	+
	38 countries		Bhattacharya, Paramati, Ozturk and Bhattachary (2016)	Real GDP at 2005 prices US dollars	Labour	Total labour force	Cointegration techniques	1991-2012	+
	OECD countries	Macroeconomic conditions	Dar and AmirKhalkhali (2002)	Annual growth rates of real GDP	investment	real gross fixed capital formation	Random coefficients model	1971–1999	+

Type of analyse	Countries	Determinant of economic growth	Authors	EG measurement	Variable	Proxy	Method	Period	Result
	OECD countries				Relative government size	Product of Private Credit Ratio	Random coefficients model	1971–1999	-
	ten OECD countries and China.		Shan (2005)	Rate of change of real GDP	Productivity	Rate of change of productivity	VAR approach	1985–1998	+
	ten OECD countries and China.				Investment	rate of change of total capital expenditure	VAR approach	1985–1998	+
	Greece, Portugal and Spain		Dunne and Nikolaidou (2005)	Real Growth of GDP	Military spending	share of military spending in GDP	cointegrating VAR framework, Granger causality techniques	1960-2002	0
	Portugal compares its composition with that of Spain, Greece and Ireland		Amador and Coimbra (2007)	Average real GDP growth rate	Capital	Stock of capital as a percentage of GDP	Stochastic Frontiers, Bayesian Methods.	1960- 2005	+
	14 countries		Luintel, Khan, Arestis and Theodoridis (2008)	Real per capita GDP growth	Physical capital stock	Real gross fixed investment	DynamicHeterogeneous Panel Estimator, Fully Modified OLS (FMOLS)	1976-2005	+
	38 countries		Bhattacharya, Paramati, Ozturk and Bhattachary (2016)	Real GDP at 2005 prices US dollars	Capital stock	Real gross fixed capital formation in constant 2005 US dollars	Cointegration techniques	1991-2012	+
	Ten OECD countries and China.	Institutions	Xu (2000)	Growth of GDP per capita	Financial development	Total bank deposits in GDP	VAR approach	1960-1993	+
	14 countries		Shan (2005)	Rate of change of real GDP	Credit	Total credit	VAR approach	1985–1998	+
	41 countries		Luintel, Khan, Arestis and Theodoridis (2008)	Real per capita GDP growth	Financial developmennt	Finance Size - product of Private Credit Ratio and Stock Market Capitalization Ratio; and Finance Activity -product of Private Credit Ratio and Stock Market Value Traded Ratio.	DynamicHeterogeneous Panel Estimator, Fully Modified OLS (FMOLS)	1976-2005	+
	14 countries				Financial structure	Structure Activity - ratio of Stock Market Total Value Traded to Private Credit and Structure-	DynamicHeterogeneous Panel Estimator, Fully Modified OLS (FMOLS)	1976-2005	+

Type of analyse	Countries	Determinant of economic growth	Authors	EG measurement	Variable	Proxy	Method	Period	Result
						Size -ratio of Stock Market Capitalization to Private Credit			
	PIIGS' economies		Ferraz and Duarte (2015)	Real growth rates of GDP at 2010 prices	Macroeconomy	Public Debt-to-GDP Ratio	Prais-Winsten estimation method	1974-2014	-
	38 countries	Natural resources and geography	Bhattacharya, Paramati, Ozturk and Bhattachary (2016)	Real GDP at 2005 prices US dollars	Renewable energy consumption	Stock Market Value Traded Ratio	Cointegration techniques	1991-2012	+
	38 countries				Non- renewable energy consumption	Non-renewable energy consumption billion kilowatthours	Cointegration techniques	1991-2012	0
	Portugal, Italy, Greece,Spain and Turkey (PIGST)		Fuinhas and Marques (2012)	GDP at 2000 prices	primary energy consumption	primary energy consumption in million tons oil equivalent	ARDL bounds test approach	1965-2009	0

Table A2: Summary of the empirical studies on the relationship between research output and economic growth

	Studies	Countries	Period	Proxy for economic growth	Proxy for research output (RO)/ performance (RP)	Method	Result	
Global research output	De Moya-Anegón and Herrero-Solana (1999)	Latin-American countries	1980-1990	Real GDP	Number of articles in journals	Correlation	Positive correlation	
	Lee et al. (2011)	24 countries	1981-2007	Nominal GDP (million USD)	Number of publications	Causality analysis	RO→EP	Australia, Austria, Germany, India, Netherlands
							EP→RO	China, Israel, Italy, Norway, Spain, US
							RO→EP & EP→RO	Brazil, Japan, Singapore, South Korea, Taiwan
							No causality	Belgium, Canada, Denmark, Finland, France, Poland, Sweden, Switzerland, UK
	Inglesi-Lotz et al. (2014)	US	1981–2011	Real GDP	Share of number of publications of the country to the rest of the world	Causality analysis	RO→EG	
	Inglesi-Lotz et al. (2015)	BRICS countries (Brazil, Russia, India, China, and South Africa)	1981–2011	Real GDP	Share of number of publications of the country to the rest of the world	Causality analysis	RP→EG	India
							No causality	Brazil, Russia, China, South Africa
	Ntuli et al. (2015)	34 OECD	1981–2011	Real GDP	Total number of articles published	Causality analysis	RO→EG	Finland, Hungary, Mexico, US
							EG→RO	Canada, France, Italy, New Zealand, the UK, Austria, Israel, Poland
							No causality	Australia, Belgium, Germany, Japan, Luxembourg, Netherlands, New Zealand, Portugal, Spain, Sweden, Turkey, Switzerland, Austria, Chile, Czech Republic, Denmark, Estonia, Greece, Norway, Slovakia, Slovenia
	Odhiamb and Ntenga (2016)	South Africa	1986-2012	Real GDP per capita	Number of research publications	autoregressive distributed lag (ARDL)	RO→EG	
	Hatemi-J *et al.* (2016)	G7 countries	1981-2012	Real GDP	Number of research papers published by the % of the total numbers of the papers published in the world	Asymmetric panel causality test of Hatemi-J (2011); VAR-SUR(p) model	RO→EG	UK
							No causality	Canada, France, Germany Japan, Italy, US
	Kumar et al. (2016)	China and US	1981–2012	Real GDP per worker	Number of research publications per worker	autoregressive distributed lag (ARDL)	EP→RO	US
							RO→EP & EP→RO	China
	Solarin and Yen (2016)	169 countries	1996–2013	Real per capita GDP	▪ **Research publication per capita** (proxy for HC) ▪ Initial income ▪ Physical capital per capita ▪ Population growth rate	System GMM	+++	
	Dkhili and Oweis (2018)	43 countries in sub-Saharan Africa	1996-2015	GDP	number of publications per year, number of citation per document	panel data analysis (fixed and random), system GMM	number of publications per year	positive and significant effect
							number of citation per document	insignificant

	Studies	Countries	Period	Proxy for economic growth	Proxy for research output (RO)/ performance (RP)	Method	Result
	Onyancha (2020)	48 countries in sub-Saharan Africa	1991-2011	GDP per capita, GDP, CPI and GNI	average number of papers, number of citations, average number of citations per article, H-Index	Correlation and regression analyses	RO→EP & EP→RO
Research output by field	Hart and Sommerfeld (1998)	US, Canada, Great Britain, Australia, India	1970-1996	Nominal GDP (million USD)	Nº of research articles published by the **chemical engineering** academic community	Correlation	Strong positive correlation
	Jin (2009)	5 East Asian Economies	1969–2004	Real GDP	Research publication per million people in **Economics**	Causality analysis	Korea and Taiwan: RO → EG Hong Kong: RO ←→EG Japan: EG → RO Singapore: 0
	Jin (2010)	Japan	1970–2004	Real per capita GDP	Research publication per million people in **Economics** - proxy for the quality of education	Causality analysis, Impulse responses	EG →RO
	Yasgül and Güris (2016)	Turkey	1981–2013	Real GDP	Share of number of publications on **biotechnology** of the country to the rest of the world	Causality analysis - bootstrapped Granger causality	RO→EP
	Vinkler (2008)	10 Central and Eastern European (CEE) countries; 14 EU; US; Japan		Real GDP per capita	Number of articles in journals per capita	Correlation	Global: 0 Clinical Medicine; Mathematics; Chemistry; Physics: Engineering: the patterns of publications vary among countries
	Jin and Jin (2013)	34-49 countries	1975–2003	Average annual growth rate of per capita real GDP	Research publications per million people	Linear regression	Global: +++ RO in basic science and engineering: +++ RO in Economics and business: ++ [smaller effect]
	Zaman et al. (2018)	Top twenty nations of the world for the sciences and social sciences	1980–2011	Real GDP	<u>research productivity:</u> number of publications <u>**in sciences and social sciences**</u> research & development (R&D), expenditures and researchers involved in R&D activities	Causality analysis	RO→EP: Turkey, Russia, South Korea, Canada, UK, China EP→RO: Germany, Japan, France, Sweden RO→EP & EP→RO: United States, Italy, Spain, Australia, India, Netherlands, Brazil, Switzerland, Taiwan, and Poland
	Jaffe et al. (2013)	101 countries	1982; 1996; 1998; 2000; 2005	Real GDP per capita	"Revealed Comparative Advantages" (RCA) of the scientific publication effort [ratio country's publications in a given discipline or area of science in its total number of publications/ the world's number of publications in that same discipline in the total world's publications.	Joining Tree Cluster Analysis; correlations	Countries with higher relative productivity in **basic sciences** (e.g., physics and chemistry) have the highest economic growth in the following five years compared to countries with a higher relative productivity in **applied sciences** (e.g., medicine and pharmacy).
	Antonelli & Fassio (2016)	13 countries	1998-2008	Total Factor Productivity Labour productivity	▪ **Expenditures** in Higher Education R&D in 'area j' (HERD*hs_grad in 'area j'/ total number of graduates). Area j= hard, social, medical sciences and humanites ▪ share of manufacturing in employment, ▪ openness to trade number of patent applications	Fixed effects panel model	Hard sciences and social sciences contribute more to TFP growth than medical sciences and human sciences.
		South Africa		Real GDP			Global: RP → EG

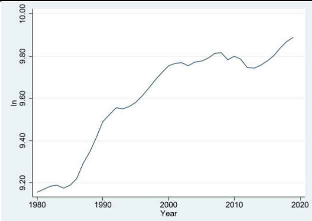
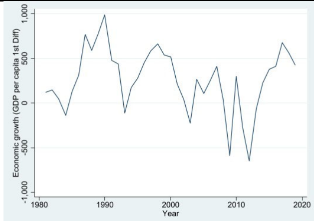
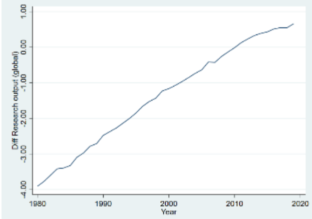
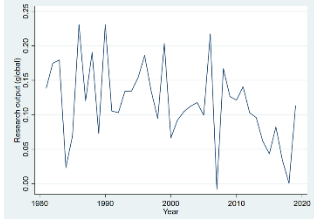
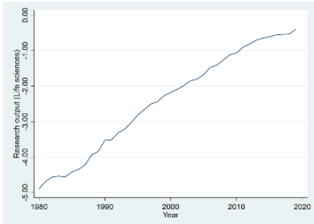
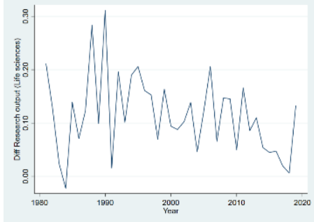
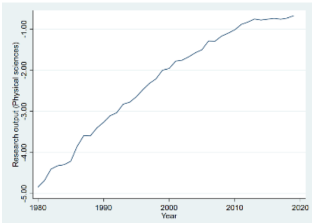
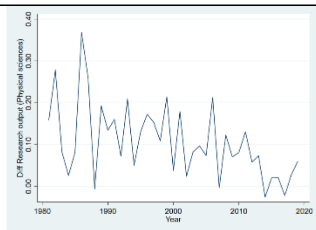
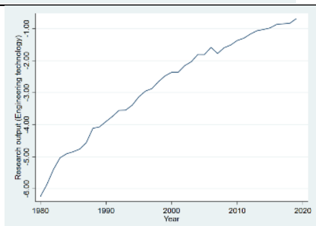
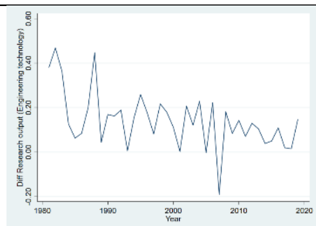
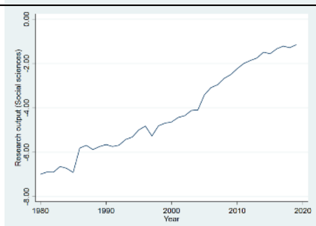
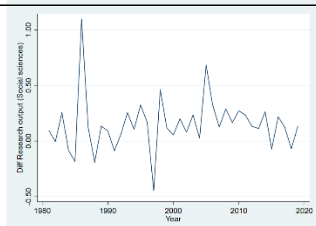
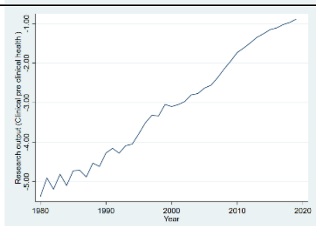
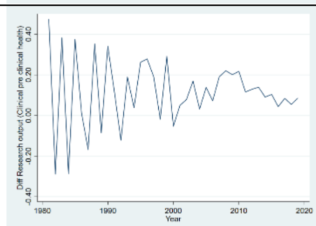
<table>
<tr><th></th><th>Studies</th><th>Countries</th><th>Period</th><th>Proxy for economic growth</th><th>Proxy for research output (RO)/ performance (RP)</th><th>Method</th><th colspan="2">Result</th></tr>
<tr><td rowspan="5"></td><td>Inglesi-Lotz and Pouris (2013)</td><td></td><td>1980-2008</td><td></td><td>Share of number of publications of the country to the rest of the world</td><td>Causality analysis - autoregressive distributed lag (ARDL)</td><td colspan="2">The same relationship is confirmed for individual fields of science (biology and biochemistry, chemistry, material sciences, physics, psychiatry and psychology).</td></tr>
<tr><td rowspan="4">Laverde-Rojas and Correa (2019)</td><td rowspan="4">91 countries</td><td rowspan="4">2003-2014</td><td rowspan="4">Index of economic complexity</td><td rowspan="4">▪ Scientific productivity (number of publications in all the scientific disciplines).
▪ patent applications (residents) per capita.
▪ Human Capital - years of schooling.
▪ GDP per capita.
▪ institutional indicator - Corruption Perception Index.
population size</td><td rowspan="4">System GMM</td><td colspan="2">All countries</td></tr>
<tr><td colspan="2">Global: +
BGM biochemistry, genetics and molecular biology: 0
EN engineering: ++
MS materials science: 0
MTH mathematics: +
PA physics and astronomy: +</td></tr>
<tr><td>Low income countries</td><td>High income countries</td></tr>
<tr><td>Global: 0
BGM: 0
EN: 0
MS: +++
MTH: 0
PA: +++</td><td>Global: +++
BGM: +++
EN: +++
MS: +++
MTH: +++
PA: +++</td></tr>
</table>

Table A3: The scientific impact of articles published relative to the World (from the highest to the lowest) and countries' level of technology and ICT development

Country	The scientific impact of articles published relative to the world	Ranking of most technologically advanced countries	ICT Development Index 2017	Income Group	Causality from RO to EG	Causality from EG to RO	Mutual causality	No causality from RO to EG
Switzerland	1.62120	11	3	High income			Zaman et al. (2018)*	Lee et al. (2011); Ntuli et al. (2015)
United States	1.57775	5	16	High income	Inglesi-Lotz et al. (2014); Ntuli et al. (2015)	Lee et al. (2011), Kumar et al. (2016)	Zaman et al. (2018)*	Hatemi-J et al. (2016)
Netherlands	1.56005	3	7	High income	Lee et al. (2011)		Zaman et al. (2018)*	Ntuli et al. (2015)
Denmark	1.51335	4	4	High income				Lee et al. (2011); Ntuli et al. (2015)
Sweden	1.47010	2	11	High income		Zaman et al. (2018)**		Lee et al. (2011); Ntuli et al. (2015)
United Kingdom	1.35993	12	5	High income	Hatemi-J et al. (2016), Zaman et al. (2018)*	Ntuli et al. (2015)		Lee et al. (2011)
Canada	1.34005	14	29	High income	Zaman et al. (2018)*	Ntuli et al. (2015)		Lee et al. (2011), Hatemi-J et al. (2016(
Belgium	1.32947	13	25	High income				Lee et al. (2011); Ntuli et al. (2015)
Finland	1.32500	7	22	High income	Ntuli et al. (2015)			Lee et al. (2011)
Israel	1.27999	29	23	High income		Lee et al. (2011), Ntuli et al. (2015)		
Norway	1.24876	1	8	High income		Lee et al. (2011)		Ntuli et al. (2015)
Germany	1.22423	19	12	High income	Lee et al. (2011)	Zaman et al. (2018)*		Ntuli et al. (2015); Hatemi-J et al. (2016)
Singapore	1.21409	6	18	High income			Leet et al. (2011)	Jin (2009)*
France	1.21041	22	15	High income		Ntuli et al. (2015); Zaman et al. (2018)*		Lee et al. (2011); Hatemi-J et al. (2016)
Austria	1.20565	25	21	High income	Lee et al. (2011)			Ntuli et al. (2015)
Hong Kong	1.18389	10	6	High income			Jin (2009)*	
Australia	1.16974	15	14	High income	Lee et al. (2011)		Zaman et al. (2018)*	Ntuli et al. (2015)
Italy	1.12405	37	47	High income		Lee et al. (2011); Ntuli et al. (2015)	Zaman et al. (2018)*	
New Zealand	1.11428	23	13	High income				Ntuli et al. (2015)
Estonia	1.08418	20	17	High income				Ntuli et al. (2015)

Country	The scientific impact of articles published relative to the world	Ranking of most technologically advanced countries	ICT Development Index 2017	Income Group	Causality from RO to EG	Causality from EG to RO	Mutual causality	No causality from RO to EG
Japan	1.03286	21	10	High income		Jin 2009; Jin 2010; Zaman et al. (2018)*	Leet et al. (2011)	Jin (2009)*, Ntuli et al. (2015); Hatemi-J et al. (2016)
Greece	0.98874	43	38	High income				Ntuli et al. (2015)
Spain	0.97398	18	27	High income		Lee et al. (2011)	Zaman et al. (2018)*	Ntuli et al. (2015)
Luxembourg	0.93301	16	9	High income				Ntuli et al. (2015)
Portugal	0.91950	32	44	High income				Ntuli et al. (2015)
Hungary	0.89239	35	48	High income	Ntuli et al. (2015)			
Taiwan	0.86429	17	-	High income	Jin (2009)*		Leet et al. (2011); Zaman et al. (2018)*	
Chile	0.81517	49	56	Upper middle income				Ntuli et al. (2015)
Slovenia	0.78738	33	33	High income				Ntuli et al. (2015)
South Korea	0.77096	9	2	High income	Jin (2009)*, Zaman et al. (2018)*		Leet et al. (2011)	
South Africa	0.76728	61	92	Upper middle income	Inglesi-Lotz and Pouris (2013)*, Odhiamb and Ntenga 2016			Inglesi-Lotz et al. (2015)
Czech Republic	0.74939	28	43	High income				Ntuli et al. (2015)
Mexico	0.68608	50	87	Upper middle income	Ntuli et al. (2015)			
China	0.68344	38	80	Upper middle income	Zaman et al. (2018)*	Lee et al. (2011)	Kumar et al. (2016)	Inglesi-Lotz et al. (2015)
Poland	0.62963	34	49	High income			Zaman et al. (2018)*	Lee et al. (2011), Ntuli et al. (2015)
Brazil	0.61796	55	66	Upper middle income			Leet et al. (2011); Zaman et al. (2018)*	Inglesi-Lotz et al. (2015)
Slovakia	0.61563	41	46	High income				Ntuli et al. (2015)
India	0.57304	60	134	Upper middle income	Lee et al. (2011); Inglesi-Lotz et al. (2015)		Zaman et al. (2018)*	
Turkey	0.55199	52	67	Upper middle income	Yasgül and Güris 2016, Zaman et al. (2018)*			Inglesi-Lotz et al. (2015); Ntuli et al. (2015)
Russia	0.43312	46	45	Upper middle income	Zaman et al. (2018)*			Inglesi-Lotz et al. (2015)

Table A4: Graphics of the relevant variables in levels and first differences

		Levels	First differences
Economic growth (GDP per capita)			
Research output	Global		
	Life sciences		
	Physical Sciences		
	Engineering Technology		
	Social Sciences		
	Clinical Pre- Clinical Health		

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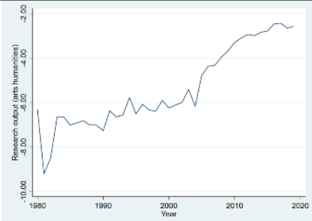
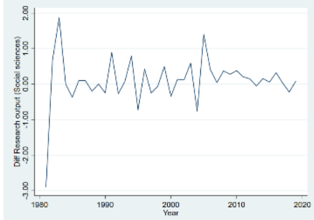
<tr><td></td><td>Arts & Humanities</td><td>
</td><td>
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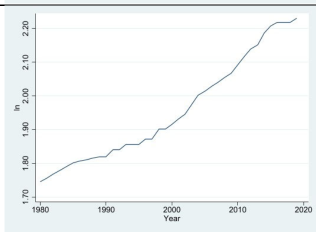
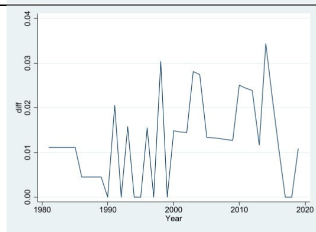
<tr><td colspan="2">Human capital</td><td>
</td><td>
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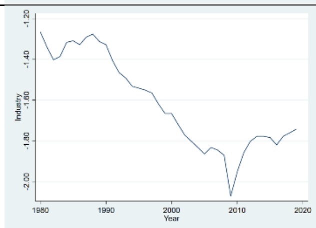
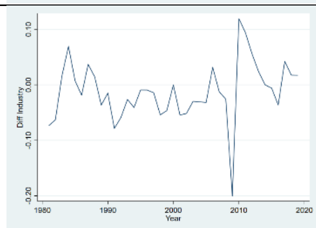
<tr><td colspan="2">Structural change</td><td>
</td><td>
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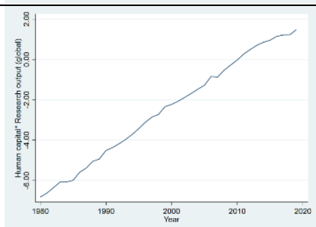
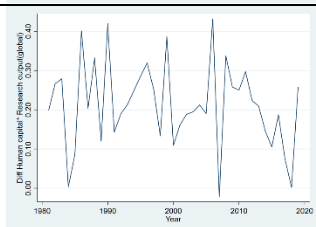
<tr><td rowspan="4">Interaction between human capital and research output</td><td>Global</td><td>
</td><td>
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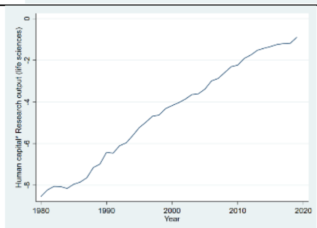
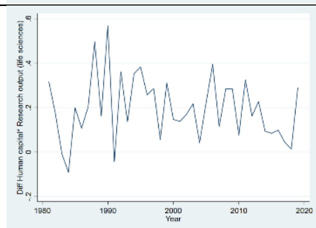
<tr><td>Life sciences</td><td>
</td><td>
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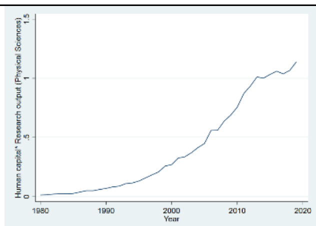
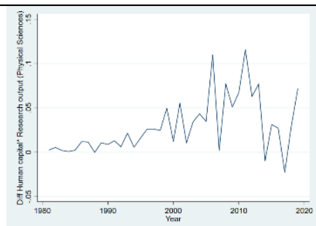
<tr><td>Physical Sciences</td><td>
</td><td>
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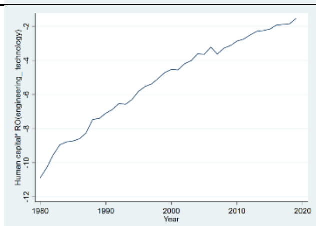
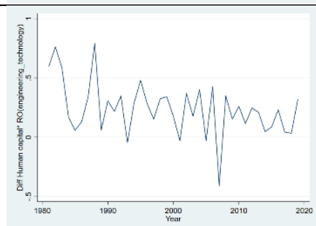
<tr><td>Engineering Technology</td><td>
</td><td>
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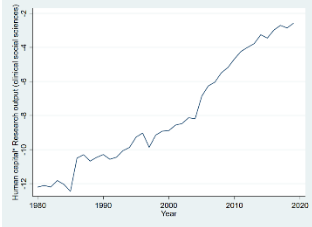
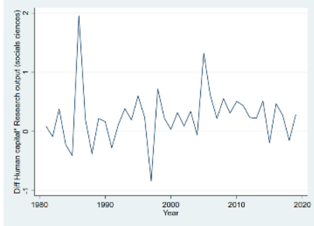
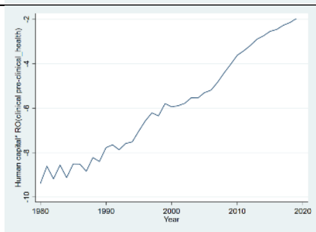
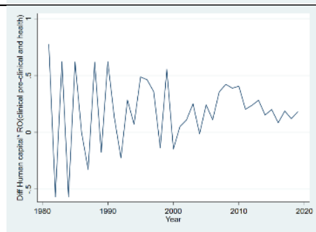
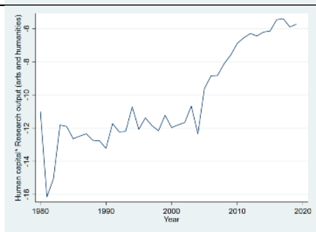
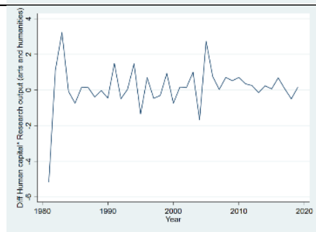
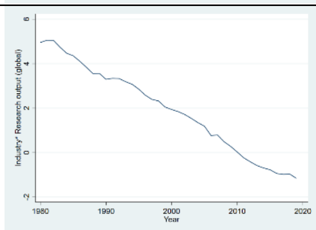
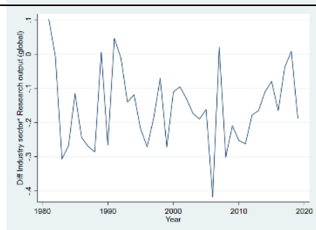
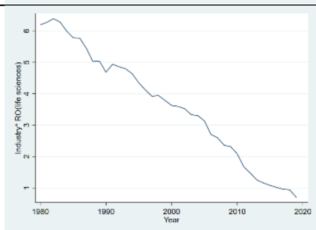
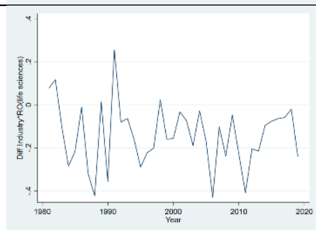
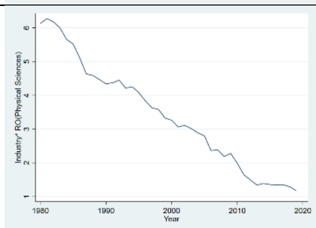
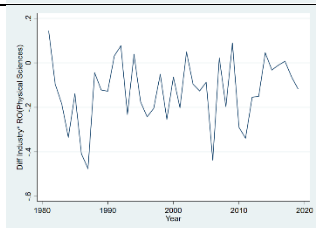
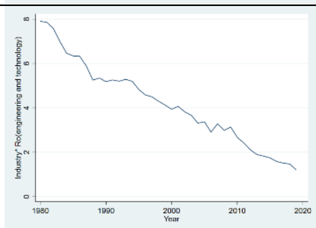
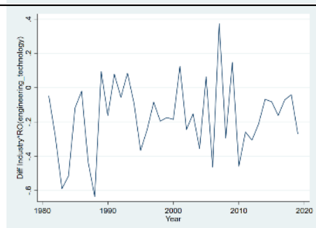
	Social Sciences		
	Clinical Pre- Clinical Health		
	Arts & Humanities		
Interaction between structural changes and research output	Global		
	Life sciences		
	Physical Sciences		
	Engineering Technology		

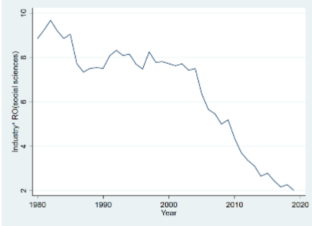
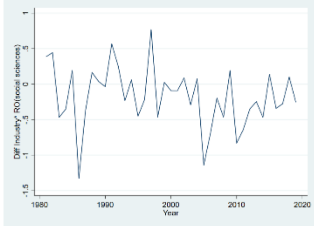
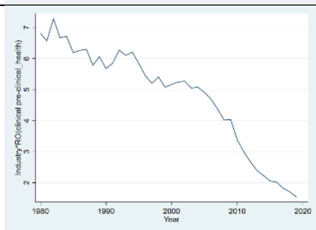
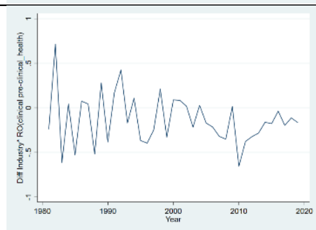
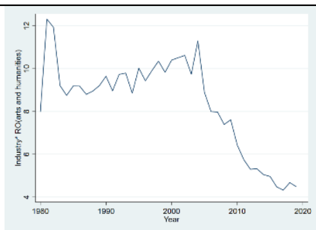
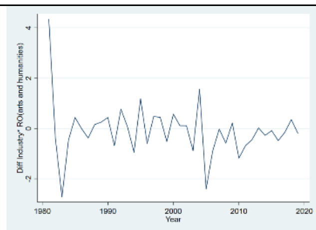
	Social Sciences		
	Clinical Pre- Clinical Health		
	Arts & Humanities		

Table A5: Johansen cointegration Trace test – the number of cointegration vectors [Economic Growth (GDP pc growth) and Research Output]

		None	At least 1	At least 2	At least 3	At least 4	At least 5
Global RO	**Trace statistic**	214.21**	118.63**	73.17**	43.16**	19.85**	6.04
	5% critical value	82.49	59.46	39.89	24.31	12.53	3.84
Life sciences	**Trace statistic**	204.72**	124.16**	77.06**	41.95**	17.88**	5.62
	5% critical value	82.49	59.46	39.89	24.31	12.53	3.84
Physical Sciences	**Trace statistic**	265.42**	170.60**	100.92**	48.29**	14.57**	
	5% critical value	94.15	68.52	47.21	29.68	15.41	
Engineering Technology	**Trace statistic**	241.58**	169.71**	102.95**	53.32**	22.75**	0.28
	5% critical value	94.15	68.52	47.21	29.68	15.41	3.84
Social Sciences	**Trace statistic**	228.80**	115.76**	72.07**	35.96**	12.15	
	5% critical value	94.15	68.52	47.21	29.68	15.41	
Clinical Pre- Clinical Health	**Trace statistic**	278.13**	174.54**	103.33**	46.79**	18.65**	6.76**
	5% critical value	94.15	68.52	47.21	29.68	15.41	3.76
Arts & Humanities	**Trace statistic**	187.22**	111.90**	65.09**	25.42**	11.84	
	5% critical value	82.49	59.46	39.89	24.31	12.53	

Table A6: Long-term relations of Economic Growth (GDP pc growth) and Research Output, Portugal, 1980-2019

		Global RO	Hard sciences				Soft Sciences	
			Life sciences RO	Physical Sciences RO	Engineering Technology RO	Social Sciences RO	Clinical Pre-Clinical Health RO	Arts and Humanities RO
Research Output (RO)		**2.172*** (0.225)**	**0.865*** (0.095)**	**0.278*** (0.085)**	**3.204* (1.756)**	**0.600*** (0.031)**	**-2.564*** (0.191)**	**0.061*** (0.022)**
Human capital (HC)		**1.969*** (0.136)**	**0.577*** (0.056)**	**1.758*** (0.523)**	**-3.306** (1.310)**	**-1.227*** (0.103)**	**1.000** (0.410)**	**-0.156** (0.062)**
RO*HC		**-1.107*** (0.164)**	**-0.415*** (0.062)**	-0.235 (0.163)	**-2.186** (0.943)**	**-0.323*** (0.030)**	**1.443*** (0.124)**	**-0.074*** (0.020)**
Structural change (SC)		**2.378*** (0.173)**	**0.767*** (0.070)**	**1.102*** (0.176)**	0.681 (0.219)	**0.260*** (0.079)**	**-1.071*** (0.265)**	**-0.168** (0.073)**
RO*SC		-0.071 (0.084)	**0.083*** (0.025)**	**0.263*** (0.075)**	**-0.822*** (0.249)**	**-0.067*** (0.016)**	**0.153* (0.082)**	**-0.047*** (0.013)**
Lags		4	4	3	4	4	4	4
VECM specification		None	None	Constant	Constant	Constant	Constant	None
No. of cointegrating vectors		5	5	4	5	4	5	4
Jarque-Bera test (overall) (1)		8.939 (0.708)	6.815 (0.869)	17.520 (0.131)	9.950 (0.620)	8.806 (0.719)	10.974 (0.531)	16.114 (0.186)
Lagrangemultiplier test (2)	Lag 1	0.926	0.986	0.654	0.633	0.637	0.460	0.871
	Lag 2	0.001	0.007	0.551	0.087	0.625	0.246	0.763
Eigenvalue stability condition (3)		0.560	0.486	0.336	0.095	0.610	0.426	0.335

Table A7: Short-run Granger (non-) causality test, GDP per capita growth

The null hypothesis	Global RO	Hard Sciences				Soft Sciences	
		Life sciences RO	**Physical Sciences RO**	**Engineering Technology RO**	**Social Sciences RO**	**Clinical Pre-Clinical Health RO**	**Arts and Humanities RO**
Research Output (RO) *does not* Granger cause Economic growth (EG)	0.151 (0.098)	**0.151*** **(0.083)**	0.064 (0.041)	0.193 (0.144)	0.045 (0.056)	0.061 (0.077)	0.029 (0.056)
Human capital (HC) *does not* Granger cause EG	**0.371*** **(0.216)**	**0.366**** **(0.163)**	0.305 (0.257)	0.193 (0.142)	0.081 (0.170)	0.119 (0.191)	0.092 (0.153)
The interaction between RO and HC *does not* Granger cause EG	-0.066 (0.064)	-0.063 (0.055)	-0.027 (0.083)	-0.086 (0.085)	-0.009 (0.041)	-0.016 (0.054)	-0.008 (0.044)
Structural Change (SC) *does not* Granger cause EG	**0.191***** **(0.048)**	**0.225***** **(0.064)**	**0.240***** **(0.064)**	**0.240***** **(0.070)**	**0.236***** **(0.087)**	**0.231***** **(0.088)**	**0.198*** **(0.108)**
The interaction between RO and SC *does not* Granger cause EG	0.037 (0.032)	0.048 (0.032)	0.052 (0.035)	0.035 (0.031)	0.016 (0.020)	0.021 (0.030)	0.008 (0.023)
EG *does not* Granger cause RO	-0.354 (0.459)	-0.637 (0.592)	**-1.097*** **(0.651)**	0.079 (1.137)	0.085 (1.828)	0.400 (1.233)	1.677 (3.266)
EG *does not* Granger cause HC	-0.074 (0.098)	-0.067 (0.101)	0.035 (0.085)	0.038 (0.117)	0.027 (0.127)	0.007 (0.109)	0.136 (0.128)
EG *does not* Granger cause SC	**-1.071**** **(0.532)**	**-0.995*** **(0.515)**	-0.688 (0.569)	**-1.050*** **(0.560)**	**-1.024**** **(0.501)**	**-1.263***** **(0.468)**	**-1.406***** **(0.532)**
RO *does not* Granger cause HC	**-0.244***** **(0.056)**	**-0.166**** **(0.050)**	-0.025 (0.019)	**-0.305***** **(0.099)**	-0.025 (0.040)	-0.018 (0.049)	-0.039 (0.041)
HC *does not* Granger cause RO	0.771 (0.574)	-0.562 (0.573)	**2.825***** **(0.915)**	-0.207 (0.954)	**7.361***** **(1.765)**	**3.604***** **(1.384)**	**5.587**** **(2.849)**
RO *does not* Granger cause SC	**-0.771**** **(0.304)**	**-0.935***** **(0.254)**	**-0.248*** **(0.129)**	0.362 (0.475)	**-0.783***** **(0.159)**	**-1.127***** **(0.211)**	**-0.642***** **(0.171)**
SC *does not* Granger cause RO	**-0.230*** **(0.127)**	-0.327 (0.223)	-0.267 (0.228)	-0.531 (0.471)	**-2.680***** **(0.895)**	-0.263 (0.640)	**-6.313***** **(2.015)**

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